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ABSTRACT

This booklet contains project-oriented lessons and hands-on activities developed to integrate steel recycling, natural resource conservation, and solid waster management into science learning. Each lesson is presented in capsule form in an introductory section called, "Lessons at a Glance." The first lesson, "Supply & Demand," includes the activities "Quenched and Tempered Steel" and "Stretch and Strain." The activities included in the second lesson, "Collect & Haul," are "Fluff Stuff" and "Jumping Metal." "What's a MRF?" and "Steel Home" are the activities included with the third lesson, "Sort & Produce." Also included are a cross-reference chart of activities to physics concepts and critical thinking skills, a glossary, student worksheets, resource list, and teacher evaluation form. (MKR)

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Cycles for Science

ED 393 651

Physics

Curriculum Supplement for Grades 9-12

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STEEL CYCLES ®

A Steel Cycles Program from the ***Steel Recycling Institute***

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Foreword:
Steel Recycling Institute

The Steel Recycling Institute (SRI) is dedicated to promoting and sustaining steel recycling across the country. The SRI recognizes the value of incorporating recycling and solid waste management information into the educational process and encourages responsible solid waste handling. ***Cycles for Science*** provides teachers and students with a greater understanding of steel and steel can recycling and encourages responsible solid waste handling practices.

Steel is America's most recycled material. Steel cans and other steel products are recycled into a variety of new steel products. A steel can may become part of a car, a bridge or perhaps a child's toy. Since steel can be recycled infinitely, the cycle continues as steel products are again recycled. Steel cans are collected for recycling through a variety of programs, including curbside, drop-off, multi-material buyback, and commercial/institutional recycling. In some communities, steel cans and other household steel products are collected for recycling automatically through magnetic separation at resource recovery facilities.

Recycling helps the environment, conserves natural resources and saves energy. The SRI is proud to help provide opportunities for solid waste management education. While this program focuses on steel and steel can recycling, the SRI supports the recycling of all recyclable materials and promotes integrated solid waste management practices. Students who learn about recycling today will be well prepared for the resource management of tomorrow.

Bill

William M. Heenan, Jr.
President

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About Cycles for Science

Welcome to the *Cycles for Science* program designed by the Steel Recycling Institute to assist secondary teachers and students (grades 9—12) in meeting state and local goals for learning in biology, chemistry, general science and earth science, and physics. Curriculum supplements in each of these core areas of science contain project-oriented lessons and hands-on activities. Also available is a curriculum supplement for community volunteer projects, appropriate for student groups and community organizations.

The motivation for creating *Cycles for Science* was requests from secondary teachers for activities which bring real-life science into the classroom. The goal of this program is to integrate steel recycling, natural resource conservation, and solid waste management into science learning.

Cycles for Science was developed in cooperation with secondary teachers and solid waste management professionals and is part of the Steel Cycles program for kindergarten through grade 12.

The Steel Recycling Institute

The Steel Recycling Institute (SRI) assists community leaders, recyclers, business people, and educators in developing steel recycling programs and raising public awareness. Located in Pittsburgh, Pennsylvania, the SRI has established a network of regional offices to help communities conduct steel recycling activity within existing programs. To supplement recycling activity and encourage long-term commitment to responsible solid waste management practices, the SRI is working toward the development of comprehensive educational programs.

Lessons at a Glance

Cycles for Science Physics is designed to assist secondary teachers in meeting state and local goals for learning in physics. This "user-friendly" curriculum supplement consists of three lessons, each containing two activities with a common background that provides in-depth information not usually found in a high school textbook. The lessons are complete with teacher and student sections that are ready to copy, and with graphics which may be copied onto transparencies or used as handouts. Activities may be easily implemented using materials and equipment commonly found in a science lab or local retail store. The Steel Recycling Institute (SRI) supports the philosophy of "reduce, reuse and recycle," and encourages teachers to make double-sided copies, use scrap materials when the activity calls for items such as newspaper and cardboard, and recycle waste materials whenever possible.

Cycles for Science activities furnish teachers with an approach to science reform, with real-life issues integrated into one or more sciences and across subject and skill areas. Teachers are encouraged to go beyond the lessons and activities by providing students with structured opportunities to get involved in school and community waste reduction and recycling programs. Such opportunities are suggested at the end of each lesson under the titles Extension and Independent Study. In addition to classroom instructional use, the lessons and activities are ideal for student science projects and individual research.

The SRI offers innovative teacher training workshops that feature activities from the *Cycles for Science* series. For more information, contact the SRI at 412/922-2772.

Objectives at a Glance

Each lesson begins with a statement of the objectives for the activities in that lesson. The objectives reflect trends in science reform and are constructed with these components:

Performance objectives

The skills the learner will develop and internalize as a result of a coherent, successful science education; a benchmark of achievement.

Instructional objectives

The immediate objectives of the activity, derived from four elements of quality science education:

Scientific inquiry: The manner in which science is done; processing skills, abilities, habits of mind, and attitudes towards scientific exploration and understanding of the natural world.

Scientific knowledge: The scientific concepts under study; principles, laws, theories, ideas and information to be learned.

Conditions for learning science: The strategies, activities and settings utilized to engage critical thinking skills and support the learning of science.

Applications for science learning: The connection with real-life situations; the opportunity for learners to use their store of scientific skills and knowledge in meaningful and innovative ways.

Lesson: Supply & Demand

Pages 1-16

Objectives

Performance objectives: In this lesson, students will show, by collecting data and examining how transformations in the crystal structure affect the physical properties of steel, how a metal may be manipulated in order to manufacture products that meet consumer demands.

Instructional objectives:

	Activity 1. Quenched and Tempered Steel	***Activity 2. Stretch and Strain***
	The learner will demonstrate an understanding of phase changes in steel, by:	The learner will predict, collect data and analyze the responses of metal wires to stretching, by:
Scientific inquiry	• analyzing the changes in brittleness of a hairpin when thermal (heating and cooling) treatments are applied	• utilizing classification systems for crystals and guitar strings to predict relative elongation strain
Scientific knowledge	• formulating and interpreting explanations for changes in brittleness	• formulating models representing changes to crystal structures due to stretching, and recording the physical implications of these changes
Conditions for science learning	• conducting simulations of thermal treatments of steel	• assembling class data of elongation strain into graphic form, and using the graphs to reinforce concepts of ductility, elasticity and deformation
Applications for science learning	• proposing uses of thermal treatments in the tool manufacturing industry	• proposing scenarios for effects of wire diameter and elongation strain on such applications as suspension bridges

The activities in this physics lesson may be integrated with other subject areas:

Quenched and Tempered Steel: chemistry, industrial arts

Stretch and Strain: mathematics, industrial arts, music

Lesson: Collect & Haul

Pages 17-32

Objectives

Performance objectives: In this lesson, students will develop a position on the concept of recycling as a resource and waste management tool, by investigating the use of magnets to collect and move ferrous and nonferrous metals.

Instructional objectives:

	Activity 3. Fluff Stuff	*Activity 4. Jumping Metal*
	The learner will demonstrate an understanding of the issues of automobile recycling by:	Given that magnetic attraction of a nonferrous metal may appear to be a contradictory observation of magnetism, the learner will demonstrate a new understanding of the phenomenon by:
Scientific inquiry	• recognizing and utilizing principles of magnetism while investigating systems for collecting ferrous metals	• constructing an aluminum foil electrical circuit to use in testing for magnetic fields
Scientific knowledge	• formulating models and hypotheses to explain the interactions of components that affect efficiency of a ferrous metal collection system	• formulating hypotheses that may account for the response of a nonferrous metal to a magnet
Conditions for science learning	• constructing a model of a magnetic drum to simulate collection of ferrous metals from a shredded automobile	• investigating the issue of recycling from a scientific perspective
Applications for science learning	• proposing solutions to current challenges for economical total car recycling	• comparing the aluminum foil circuit to an eddy current separator, and proposing how magnets may be used in recycling nonferrous metals

The activities in this physics lesson may be integrated with other subject areas:

Fluff Stuff: chemistry, earth science, industrial arts, social studies

Jumping Metal: earth science, industrial arts, social studies

Lesson: Sort & Produce

Pages 33-50

Objectives

Performance objectives: In this lesson, students will examine and develop a position on the recycling process, from sorting to the use of recycled materials in construction, by constructing models of a materials recovery facility and the framework of a house.

Instructional objectives:

	Activity 5. What's a MRF?	***Activity 6. Steel Home***
	The learner will demonstrate an understanding of the recycling process and its impact on society, by:	The learner will identify and discuss structural entities and functions relating to construction, by:
Scientific inquiry	• recognizing and utilizing physics principles in exploring the workings of a materials recovery facility (MRF)	• demonstrating various logical connections between the concepts of tension, compression, and the choice of materials for building a house
Scientific knowledge	• formulating models and hypotheses that can be used to explain the interactions of components within a MRF	• formulating hypotheses that can be used to account for regions of stress on a structure
Conditions for science learning	• constructing a model of one component of a MRF, and operating it with components constructed by other groups to simulate the sorting of recyclable materials	• constructing a model of the framework of a house to investigate the use of recycled steel in construction
Applications for science learning	• proposing scenarios for the role of a MRF in reducing waste and increasing the recycling potential of a community	• proposing construction materials suitable for use in a full scale building, and evaluating the social and ecological impact of using recycled steel

The activities in this physics lesson may be integrated with other subject areas:

What's a MRF?: industrial arts, social studies

Steel Home: industrial arts, social studies

Cross-Reference of Activities to Physics Concepts and Critical Thinking Skills

LESSON:	SUPPLY & DEMAND		COLLECT & HAUL		SORT & PRODUCE	
ACTIVITY:	1 Quenched and Tempered Steel	2 Stretch and Strain	3 Fluff Stuff	4 Jumping Metal	5 What's a MRF?	6 Steel Home
PHYSICS CONCEPTS						
Dynamics						
gravity					●	
Energy, work and power						
work			●		●	
simple machines			●		●	
Heat						
thermal effects	●					
Magnetism and electricity						
magnetism			●	●	●	
electricity				●		
States of matter						
properties of solids	●	●			●	●
crystals	●	●				
alloys	●	●				
Statics						
stress and strain	●					●
tension/compression						●
CRITICAL THINKING SKILLS						
problem solving			●		●	●
creative thinking	●	●	●		●	●
decision making				●	●	●
communication	●	●	●	●	●	●
collaboration	●	●	●	●	●	●
leadership	●	●	●	●	●	●
organization	●	●	●	●	●	●

The Steel Cycle and Cycles for Science: Linking the Process to Learning

Lesson: Supply & Demand

In this lesson, students will show, by collecting data and examining how transformations in the crystal structure affect the physical properties of steel, how a metal may be manipulated in order to manufacture products which meet consumer demands.

Objectives

Activity 1. Quenched and Tempered Steel

The learner will demonstrate an understanding of phase changes in steel, by:

- analyzing the changes in brittleness of a hairpin when thermal(heating and cooling) treatments are applied
- formulating and interpreting explanations for changes in brittleness
- conducting simulations of thermal treatments of steel
- proposing uses of thermal treatments in the tool manufacturing industry

Activity 2. Stretch and Strain

The learner will predict, collect data and analyze the responses of metal wires to stretching, by:

- utilizing classification systems for crystals and guitar strings to predict elongation strain
- formulating models representing changes to crystal structures due to stretching, and recording the physical implications of these changes
- assembling class data of elongation strain into graphic form, and using the graphs to reinforce concepts of ductility, elasticity and deformation
- proposing scenarios for effects of wire diameter and elongation strain on such applications as suspension bridges

Key Terms

Key terms are highlighted in the *Background: Student* with definitions provided in the *Glossary*.

deformation	**elastic limit**
elongation strain	**phase**
quench	**temper**

Motivation

Mold a piece of aluminum foil onto the face of a mannequin (e.g., model of the human body from the biology department). Carefully remove the foil so it retains the shape of the face.

Discuss the ability of the foil to be molded and retain its shape (malleability). Discuss other properties of metals: ductility, strength, toughness, electrical and thermal conductivity, luster.

Demonstration

Display coils of bare steel, copper, and aluminum wire of various gauges. Allow students to flex the wires. Ask the class to brainstorm uses for the different types and gauges of wires. For example, steel wire is used for heavy cable, musical wire and picture-hanging wire; copper is used for electrical wiring; aluminum is often used for electrical experimentation in the laboratory.

Background: Teacher

Content Development

Copy onto transparencies or use as handouts *Typical Unit Cells Formed by Metals* and *Slip Planes*, pages 3 and 4. Copy and distribute to each student the *Background: Student*, pages 5 and 6. Use the transparencies and background reading as references in explaining how properties of metals are determined by crystal structure.

Explain the concepts of alloys and thermal treatments. Describe deformation, stress and strain.

Optional: Copy onto a transparency *Crystal Structure of Steel* from *Cycles for Science Chemistry*, page 4. Refer to the transparency when describing the effect of the carbon atom on the body-centered cubic structure of steel.

For general information on properties of metals and crystal structure, refer to a standard physics or chemistry text. For more information on the crystal structures of iron and steel, refer to *Cycles for Science Chemistry*, "Lesson: Supply & Demand."

Extension

The following activity expands on concepts introduced in this lesson.

Press and Punch

As a class, press and punch a design of crystal structures and slip planes into a large sheet of heavy-duty aluminum foil. For patterns, use the diagrams on pages 3 and 4 or use graphics from a physics or chemistry text. Work on a soft surface, such as corrugated cardboard or several layers of newspaper. Position the patterns on the foil and trace the designs by pressing down with the cap of a ball point pen. Remove the patterns. Use the pen cap to carefully deepen impressions and a straight pin or nail to puncture holes as desired. Prepare a legend for the work utilizing the key terms. Display the finished work for other school groups to see.

An alternative activity is to build ball and stick models of the crystal structures.

Independent Study

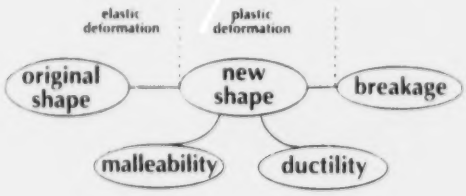
- Research methods of processing metals: hot-rolling, cold-rolling, extrusion and forging. Prepare a presentation including a discussion on how the properties of metals make these processing methods possible.

- Refer to an encyclopedia or engineering book for information on alloys of steel, aluminum and copper. Make a chart showing the various alloys and examples of products made from those alloys. Select a product and describe the properties of metals that apply to that product. Cookware is a good example of a product for which these three metals are used. Check with your local library for assistance in finding addresses and telephone numbers of cookware manufacturers.

Evaluation "Test Your Knowledge"

Evaluate student learning of the concepts introduced in this lesson. "Test Your Knowledge" suggestions:

- Create a concept map using the terms: original shape, new shape, elastic deformation, elastic limit, plastic deformation, malleability, ductility, breakage.

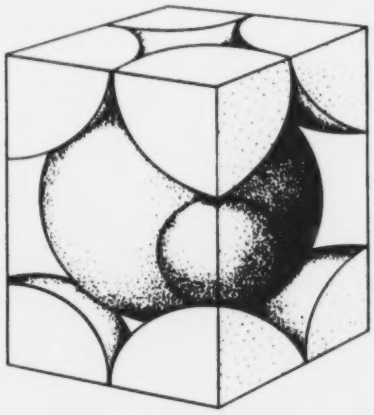


- Secure one end of a piece of sheet metal between two boards in a vise. Slowly push down on the opposite end of the metal until it bends. As you push, identify stress, strain, elastic deformation, elastic limit, and plastic deformation.

- Use the key terms to write a story for the school newspaper.

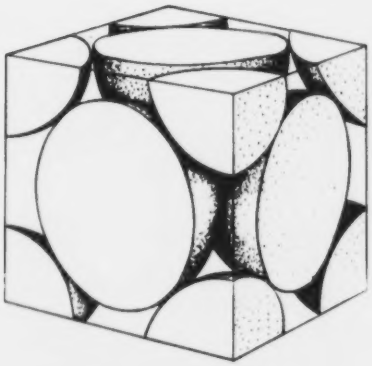
Typical Unit Cells Formed by Metals

Each sphere or part of a sphere represents a metal ion. Ions at the corners and outside faces of each unit cell are shared with neighboring unit cells. Valence electrons flow freely from ion to ion throughout the crystal.



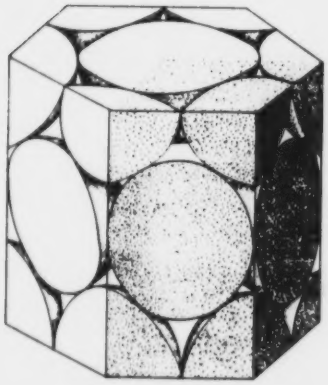
Body-Centered Cubic (BCC)

chromium, iron, molybdenum, potassium, sodium, tantalum, tungsten, vanadium



Face-Centered Cubic (FCC)

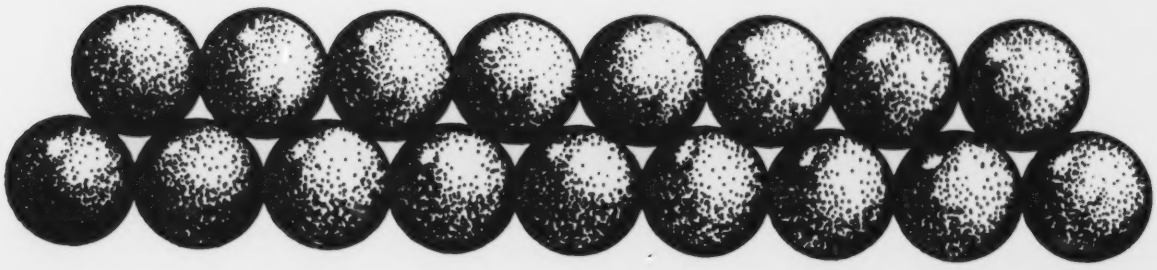
aluminum, copper, gold, lead, nickel, platinum, silver



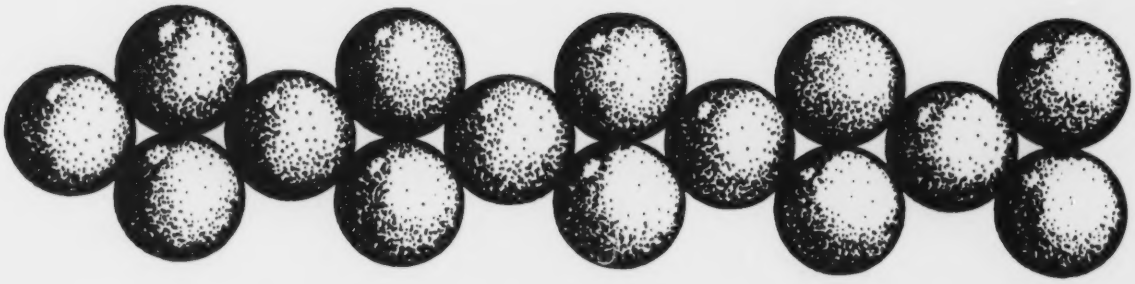
Hexagonal Close-Packed (HCP)

beryllium, cadmium, cobalt, titanium, magnesium, zinc, zirconium

Slip Planes



Face–Centered



Body–Centered

Lesson: Supply & Demand

HAVE YOU EVER WONDERED? *What properties of metals make them versatile and useful for manufacturing so many different products?*

Steel and other metals play a very important role in manufacturing. Metals have many uses throughout the manufacturing process, from the machines and tools designed to make products, to vehicles used to transport products to stores, to steel girders that support the stores, to shelves used to display the products, and finally to the actual products and their containers. The physical properties of metals and their ability to be combined with other substances make them so useful.

Crystals and Slip Planes

The properties of metals are a result of the way metal atoms are bonded in a crystal. A crystal is a three-dimensional, rigid structure composed of small, geometric unit cells repeated over and over. The unit cells can be packed in various ways to form many different types of crystals. The three types of crystals usually formed by metals are body-centered cubic (BCC), face-centered cubic (FCC), and hexagonal close-packed (HCP). The type of crystal formed depends upon the metal and the temperature.

A unique property of metals is that valence electrons are shared among the metal atoms in a crystal. This causes the bonds to be multidirectional. When a force such as hammering, pressing, or stretching is applied to a metal, the atoms in the crystal are able to slip past each other and take up new positions, yet still remain bonded together and retain the crystal structure. This leads to two significant properties of metals: malleability—also called formability - the ability to be hammered, rolled or pressed into thin sheets without breaking; and ductility, the measure of the ability to undergo change of shape without rupturing. Malleability is important for such applications as pressing out the hood of a car or molding the metal box which contains the automobile air bag. Ductility is critical for applications such as the manufacturing of wire and cable.

Slippage of atoms in a metal occurs in layers called slip planes. Slippage takes place more easily in FCC crystals than in BCC crystals because the FCC crystal is more tightly packed and symmetrical. Consequently, metals that form FCC crystals are usually even more malleable and ductile than those with BCC structures.

Locked in Place

For some applications, high malleability is required. For other applications, low malleability (and high hardness) is desired; an example is the pistons and cylinders of an automobile engine. Hardness and many other properties of metals may be manipulated to exact specifications by the addition of alloying elements and various thermal (heating and cooling) treatments.

An alloy is a solid mixture of a base metal, such as iron, aluminum or copper, with one or more alloying elements. Steel, for instance, is an alloy of iron with a low percentage of carbon, from less than 0.05 to 1.5 percent; most types of steel contain less than 0.5 percent carbon. Other elements may also be added to steel.

Solid iron normally exists as a BCC crystal. At high temperatures, however, the crystal structure of solid iron (or steel) is transformed to FCC. Carbon atoms fit into the empty spaces between FCC cells, but as the steel slowly cools, the structure reverts back to BCC. BCC cells have smaller spaces between them, so the carbon atoms no longer fit. A small percentage of carbon remains in the spaces, distorting the shape of the unit cells. This type of structure is called ferrite. Excess carbon atoms precipitate out of the metal as cementite, Fe_3C, dispersed throughout the metal like grains of pepper mixed in salt. The amount of cementite formed depends upon how much carbon is present. Ferrite and cementite **phases** (micro-regions) can exist side by side in a

sample of steel. In both phases, the presence of carbon interferes with movement of the slip planes, locking the atoms in place. Consequently the steel becomes hard.

Steel can be made even harder by **quenching** (cooling very rapidly) from very high temperatures. When the hot metal is quenched, the excess carbon does not have a chance to form cementite, but is caught in the iron to further distort the crystal. This phase is called martensite and can be thought of as a phase of internal stress. Martensitic steel is very hard, but also very brittle. **Tempering** may be performed to increase toughness (relieve the internal stress to reduce brittleness while maintaining much of the hardness). In the tempering process, quenched steel is reheated to a specific temperature, held at that temperature for a time, and then cooled at a controlled rate. The temperature, holding time and cooling rate are adjusted for the carbon content, other alloying elements and desired toughness. The resulting micro-structure is a mixture of cementite and ferrite phases, but in a somewhat different configuration than that achieved had it never entered the martensitic phase.

Quenching and tempering are just two of the thermal treatments performed on steel. The versatility of steel is due to the many possible combinations of alloying elements and thermal treatments, all of which affect the crystal structure and consequently the properties of the steel.

Elastic Limits

When a metal or other material is subjected to a force such as stretching or compression, it undergoes a change in shape referred to as **deformation**. Atoms shift from their original positions to new positions, allowing the material to change in length and width. If the atoms have not been pushed or pulled too far, they will return to their original positions when the force is removed, and the material will regain its original shape. This deformation is elastic.

If the atoms are pushed or pulled beyond the elastic limit, they will not return to their original positions when the force is removed. The metal or material retains its new shape and deformation is plastic. The **elastic limit** is the boundary between elastic and plastic deformation. A malleable, ductile material such as steel has the ability to be plastically deformed.

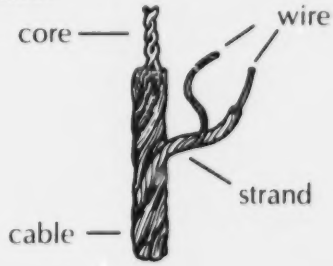
Stress and Strain

When an outside force is applied to a metal (or other substance), it causes a force within the metal called stress. The response of the metal to the stress is called strain. In general, as the stress increases, the strain does too. **Elongation** strain is a measure of the ductility of a metal, or how far it can be deformed before it ruptures. Elongation strain is the ratio of the change in length to the original length when a material is stretched.

Thick and Flexible

As the diameter of a wire increases, the flexibility decreases. Sometimes, however, it is desirable to have a thick wire that retains flexibility. For instance, in musical instruments such as guitars or violins, the lower notes are produced by strings with greater diameter, greater density, but more flexibility (less tension on the wire). A single wire thick enough to produce the lower notes would be too rigid to play. Consequently some of the strings are wound with fine wire to increase the diameter and density while maintaining flexibility (less tension on the wire).

This principle is also applied to making cable, as shown below.



Activity 1: Quenched & Tempered Steel

Objectives

The learner will demonstrate an understanding of phase changes in steel, by:

- analyzing the changes in brittleness of a hairpin when thermal (heating and cooling) treatments are applied
- formulating and interpreting explanations for changes in brittleness
- conducting simulations of thermal treatments of steel
- proposing uses of thermal treatments in the tool manufacturing industry

Time

One class period

Safety Tips

Review safe techniques for using a Bunsen burner. Advise students to be sure the hairpins have cooled before touching them with bare hands. Caution students to bend the hairpins carefully. Students must wear goggles for this activity.

Materials/Equipment

Beakers (100-mL or larger)

Bunsen burner

Forceps

Hairpins (bobby pins, new, from a single manufacturer)

Masking tape

Paper towels

Watch or stopwatch

Procedure

1. Use the figures *Typical Unit Cells Formed by Metals* and *Slip Planes*, pages 3 and 4, and the *Background: Student*, pages 5 and 6, to discuss with the class how crystal structure, addition of alloying elements, and phase changes due to thermal treatments affect the properties of steel.

2. Divide the students into lab groups. Provide each group with a beaker of cold water (100 mL is adequate), Bunsen burner, forceps, five new hairpins from the same manufacturer, a ten-centimeter strip of masking tape (enough to label the hairpins), paper towels, and a watch or stopwatch.

3. Copy and distribute to each student *Activity 1: Student*, pages 9 and 10. Inform the students that hairpins are generally made of steel. This may be demonstrated by picking up hairpins with a magnet. Review the steps to thermal treatments of hairpins and instruct lab groups to proceed with the activity.

4. *For further study:*

- Thermal Expansion of Metals

  Another effect of heat on the crystal structure of metals is thermal expansion. Demonstrate thermal expansion of a steel rod using a commercial thermal expansion unit or by building your own. (See *Thermal Expansion Unit*, page 8.) A ring stand support may be used for the rod. After demonstrating thermal expansion, ask the students to think back on the hairpin experiment, or to conduct a new experiment, to answer the following questions: Did the hairpins expand when heated in the Bunsen burner? (Yes, but because the hairpins were small, expansion was small and not readily detectable.)

How might thermal expansion be related to high temperature transformation from BCC to FCC in steel? (When the temperature of a metal or other substance is increased, its atoms tend to move farther apart, on average. In steel, the increased distance of the atoms allows the transformation to the FCC structure.)

- Tempering of Other Substances

Ask students to research the tempering of other substances, such as glass. Instruct them to describe the tempering process for this substance and compare it to the tempering process for steel.

Collecting and Analyzing Data

1. Ask students to examine the hairpins by pulling the prongs apart and bending them. Instruct students to compare flexibility/brittleness of the treated hairpins with the control, and record observations in the chart "Thermal Treatments of Hairpins," page 10. Encourage students to compare observations with predictions.

2. Ask each lab group to report their observations. Discuss variations in results.

Drawing Conclusions

Q1: How did the cooling rate affect the flexibility/brittleness of the hairpins? Which treatment transformed the steel to the martensitic phase?

A1: Slow cooling, before or after quenching, caused the hairpin to be somewhat less flexible and more brittle than the control. The hairpin may have snapped upon bending, but in a less pronounced manner than with quenching. Rapid cooling (quenching) caused a sharp increase in brittleness, so the hairpin immediately snapped upon bending. The heating and quenching treatment transformed the steel to martensitic steel.

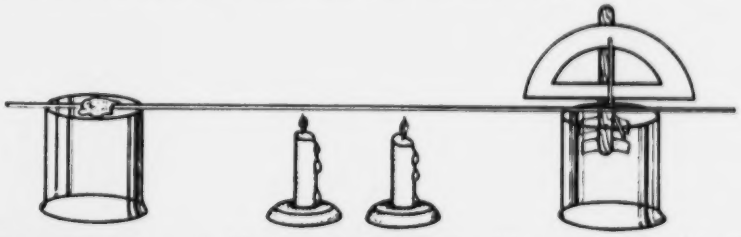
Explain to the class that although the emphasis in this activity was on the cooling treatment, the specific heating treatment is also very important in making steel.

Q2: Why are tools such as hammers often made of tempered steel? Explain.

A2: To do the job for which it is designed, a tool must be both hard and tough. For instance, a hammer must be harder than the nail to drive the nail through wood. The hammer must also be tough, so it does not shatter when it hits the nail. Tempered steel is both hard and tough.

Thermal Expansion Unit

A metal rod is secured to the beaker on the left with modeling clay. The rod rests on a thin wire on the beaker to the right.



The protractor assembly is a popsicle stick with one end taped to the back of the protractor and the other end taped to the beaker or stuck in a lump of modeling clay.

Activity 1: Quenched & Tempered Steel

Procedure

1. In this activity, you will work in lab groups to observe how heating and cooling treatments affect the properties of steel. You will need:

- 1 beaker of cold water (100 mL)
- 1 Bunsen burner
- 1 pair of forceps
- 5 new hairpins from the same manufacturer
- 10-cm strip of masking tape
- paper towels
- 1 watch or stopwatch.

Safety Tips: Exercise caution when using a Bunsen burner. Be sure the hairpins have cooled before touching them with bare hands. Bend hairpins carefully. Wear goggles for this activity.

2. Examine a hairpin.

a) Select a hairpin and manipulate it in various ways, such as pulling the prongs apart and bending the prongs. Is the hairpin flexible (bends easily) or is it brittle (breaks easily upon bending)? Record your observations in the chart "Preliminary Observations on a Hairpin," page 10. Discard this hairpin.

b) In the chart "Thermal Treatments of Hairpins," page 10, predict what will happen to flexibility/brittleness of a hairpin when it is:

- Heated and slowly cooled.
- Heated and quenched (rapidly cooled).
- Heated, quenched, and tempered (reheated and slowly cooled).

3. Prepare the hairpins for the experiment.

a) Wrap a piece of masking tape around the end of a prong of each of the four new hairpins, leaving a flap that can be labeled.

b) Label the hairpins as follows:

- Control
- Heat and slow cool
- Heat and quench
- Heat, quench, and temper

4. Perform the heating and cooling treatments.

a) Select the hairpin labeled "heat and slow cool." Using the forceps, insert the closed end of the hairpin in the Bunsen burner flame for 30 seconds. The end of the hairpin in the flame will become glowing red. Remove the hairpin from the flame. Allow it to cool in the air.

b) Select the hairpin labeled "heat and quench." Using the forceps, insert the closed end of the hairpin in the Bunsen burner flame for 30 seconds. Drop the hairpin into the beaker of cold water. After five seconds, remove the hairpin from the water and dry it.

c) Select the hairpin labeled "heat, quench, and temper." Repeat step b) on this hairpin. After removing the hairpin from the water and drying it, insert the closed end in the Bunsen burner flame once more, but for 15 seconds only. Allow the hairpin to cool slowly in the air.

Collecting and Analyzing Data

1. After all the hairpins have cooled, manipulate them by bending the prongs and pulling them apart. Compare flexibility/brittleness of the heated and cooled hairpins with the control. Record your observations in the chart "Thermal Treatments of Hairpins."

2. Compare your observations with your predictions and with the observations made by other lab groups. Discuss any differences in results.

Preliminary Observations on a Hairpin

Examine flexibility/brittleness of a hairpin by bending the prongs and pulling them apart. Record your observations below. Is the hairpin flexible (bends easily) or is it brittle (breaks easily)?

Thermal Treatments of Hairpins

Treatment	Flexibility/brittleness of hairpins after thermal treatment, compared to control (no thermal treatment)	
	Predicted	Observed
Heat and slow cool		
Heat and quench		
Heat, quench, and temper		

Drawing Conclusions

1. How did the cooling rate affect flexibility/brittleness of the hairpins? Which treatment transformed the steel to the martensitic condition?

2. Why are tools such as hammers often made of tempered steel? Explain.

Activity 2: Stretch and Strain

Objectives

The learner will predict, collect data and analyze the responses of metal wires to stretching, by:

- utilizing classification systems for crystals and guitar strings to predict elongation strain
- formulating models representing changes to crystal structures due to stretching, and recording the physical implications of these changes
- assembling class data of elongation strain into graphic form, and using the graphs to reinforce concepts of ductility, elasticity and deformation
- proposing scenarios for effects of wire diameter and elongation strain on such applications as suspension bridges

Time

One class period

Safety Tips

In an industrial setting, wires are stretched to the breaking point, then fit back together to determine the elongation strain. However, for student safety the wires will not be stretched to the breaking point in this activity. Emphasize to students that they should stretch the wires only to the point of tightness; do not allow the wires to break. Students must wear goggles for this activity.

Materials/Equipment

Board (2.5 meters in length) *

Eyebolts (screw type, 5 centimeter)

Graph paper

Guitar (6-string acoustical or electric)

Guitar strings (light gauge steel, new set)

Markers (indelible)

Meter stick

Rulers

Wire (18-gauge non-insulated, 2.5 meters each of aluminum, copper and steel)

**Two short boards may be used instead of one long board.*

Figures/Tables

Scheme of Wire Stretching Assemblies, page 13

"Class Data: Elongation Strain," page 14

Procedure

1. Set up the following stations:

Eyebolt wire.

a) Screw the eyebolts into the board so the eyebolts are two meters apart. Clamp the board to a table (or two tables pushed together). If using two boards, screw one eyebolt into each board and clamp each board to a table so the eyebolts are two meters apart.

b) Label the eyebolts #1 and #2. Draw a thin line on the board close to eyebolt #2 as shown in *Scheme of Eyebolt Assembly*, page 13. Label the line "Start." Place an indelible marker, meter stick, ruler, and the steel, copper and aluminum wires at the station.

Guitar string.

a) Lay the guitar flat on a table. Thread the new steel guitar strings so they do not sag but are not tight.

b) Label the guitar strings 1 (thinnest) through 6 (thickest). Place an indelible marker and a ruler at the station.

c) Compare the specifications of your guitar strings (check the package) with the figures given in *Elongation Strain of Guitar Strings*, page 14. If your guitar strings are different from the table, edit the table.

2. Use the *Background: Student*, pages 5 and 6, to discuss the principles of stress, strain and ductility. This activity may follow classroom discussion on Hooke's Law. Point out to students that Hooke's Law holds true only as long as the material is not stretched beyond the elastic limit; in this activity, the material is stretched beyond the elastic limit.

3. Divide the class into nine lab groups. Assign each group a different wire as listed in the chart "Class Data: Elongation Strain. "

4. Copy and distribute to each student *Activity 2: Student*, pages 15 and 16. Copy onto transparencies or use as handouts *Scheme of Wire Stretching Assemblies* and "Class Data: Elongation Strain," pages 13 and 14.

5. Show the transparency *Scheme of Wire Stretching Assemblies* and review the steps to the activity. Remind students to avoid breaking the wires and to wear goggles. Instruct groups to proceed with the activity.

Assist each lab group in calculating the elongation strain for their wire or guitar string. Place the transparency "Class Data: Elongation Strain," on the overhead projector and allow each lab group to fill in the data.

If time and resources allow, provide new sets of guitar strings and wires and arrange for groups to repeat the stretching portion of the activity.

6. *For further study:*

- The story of a wire

  Challenge the class to produce an interesting and scientifically accurate story about the structure of a guitar string or television cable, and present the story musically or by video to other classes or student groups.

Collecting and Analyzing Data

1. Assist students in making graphs using the class data. For eyebolt wires, students should construct bar graphs showing the metal compared to elongation strain. For guitar strings, students should construct line graphs showing diameter of the guitar strings compared to elongation strain. Encourage students to compare observations with predictions. Ask students to indicate on each graph the wire that was most ductile (aluminum wire, large diameter guitar string).

2. Challenge students to design experiments to test the following questions, and others which might have arisen during the activity.

- Did the lengths of the guitar strings affect the results of the stretching activity? (Utilize a setup similar to the eyebolt station to test guitar strings of the same lengths. The largest diameter string should still stretch the most.)
- Were the eyebolt wires plastically deformed? (Measure and record the height of the wire above the table at the midpoint before and after stretching. If the wire sags, plastic deformation has occurred.)

Drawing Conclusions

Q1: What is the relationship between the type of metal, ductility and elongation strain? Explain in terms of crystal structure. Describe verbally or use a series of sketches similar to Slip Planes, *page 4.*

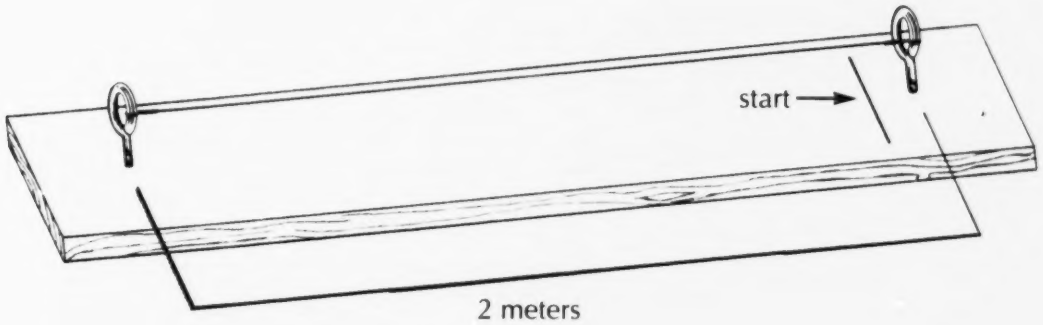
A1: Aluminum, with the greatest ductility and elongation strain, normally forms a face-centered cubic (FCC) structure, as does copper. The FCC structure allows the planes to slip past each other more easily than the body-centered cubic (BCC) structure. Steel, with the least ductility and elongation strain, forms a BCC structure at normal temperatures. The BCC structure allows slippage but not as easily as FCC.

Q2: Why are suspension bridges built with cable? How does the relationship between the diameter of a wire and elongation strain affect a suspension bridge?

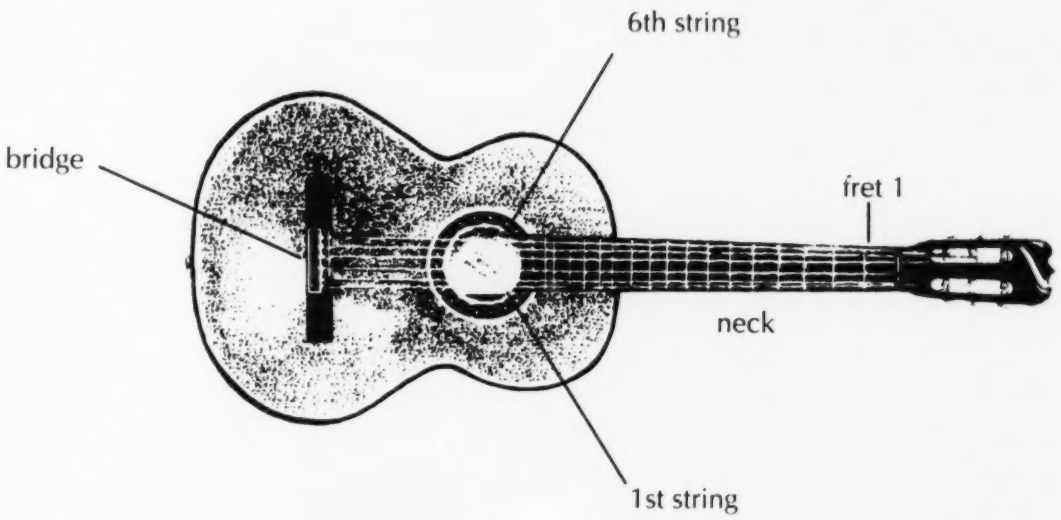
A2: In a suspension bridge, flexibility is desirable but so is the ability to bear a heavy load. A single wire thick enough to hold up a bridge would be far too rigid. This problem is solved by the use of cables. As the diameter of the cable increases, the elongation strain it can bear without breaking also increases, simply because there are more atoms available to slip past each other. The amount of stretch must be accounted for in the design of the bridge.

Scheme of Wire Stretching Assemblies

Eyebolt Assembly



Guitar



Class Data: Elongation Strain

Elongation Strain of 18 - Gauge Wires

Metal	Diameter (mm)	Elongation Strain
Lab group 1: Aluminum	1.02	
Lab group 2: Copper	1.02	
Lab group 3: Steel	1.02	

Elongation Strain of Guitar Strings

String (note, type)	Diameter (mm)	Elongation Strain
Lab group 4: 1st (E, silvered steel)	0.305	
Lab group 5: 2nd (G, phosphor bronze wound steel)	0.406	
Lab group 6: 3rd (G, phosphor bronze wound steel)	0.635	
Lab group 7: 3rd (G, phosphor bronze wound steel)	0.813	
Lab group 8: 3rd (G, phosphor bronze wound steel)	1.067	
Lab group 9: 6th (E, phosphor bronze wound steel)	1.321	

Activity 2: Stretch & Strain

Procedure

1. In this activity, you will work in lab groups to stretch a wire and calculate the elongation strain. Your teacher will assign your group a wire (aluminum, copper or steel) or a guitar string (1 - 6) to test at one of two stations. You will need graph paper for this activity. Other materials are provided at the stations.

Safety tips: Avoid breaking the wires and guitar strings. Do not force the eyebolt or the guitar key past the point of tightness. Stand back from the wires when they are being stretched. Wear goggles for this activity.

2. Observe the wires.

At each station, observe the wires and predict which will stretch the most and which will stretch the least. Record your predictions in the chart "Predictions," page 16.

3. Stretch the wires.

At your assigned station, follow the instructions for either Eyebolt Wires or Guitar Strings as described below.

Eyebolt Wires.

Record data in the chart "Eyebolt Wires," page 16.

a) Thread your assigned wire through the eyebolts as shown in *Scheme of Wire Stretching Assemblies*, page 13. Tighten the wire until it is straight but not tight.

b) Mark the wire directly above the line labeled "Start." Measure the wire between eyebolt #1 and the mark. Record the length in column (A) in the chart.

c) Tighten the wire by turning eyebolt #2 until you cannot turn it any more. **Do not apply excessive force.** Avoid breaking the wire.

d) Mark the wire directly above the line labeled "Start." Measure the change in length (the distance between the two marks). Record the change in length in column (B) in the chart.

e) Release the tension on the string by returning the eyebolt to its original position.

f) Calculate the elongation strain for your wire. Add your data to the class data.

Guitar Strings.

Record data in the chart "Guitar Strings," page 16.

a) Refer to *Scheme of Wire Stretching Assemblies*, page 13, to identify parts of a guitar.

b) Locate your assigned string on the guitar at the station. Mark the string at Fret 1 and measure the length from the bridge to the mark. Record the length in column (A) in the chart.

c) Tighten the string by turning the key until you cannot turn it any more. **Do not apply excessive force.** Avoid breaking the string.

d) Measure the change in length (the distance between Fret 1 and the mark). Record the change in length in column (B) in the chart.

e) Release the tension on the string by returning it to its original position (so the first mark lines up with Fret 1).

f) Calculate the elongation strain for your guitar string. Add your data to the class data.

Collecting and Analyzing Data

1. Use the class data to create a bar graph showing elongation strain for each type of wire (aluminum, copper, steel) and a line graph showing the diameter of guitar strings compared to elongation strain. Compare your observations to your predictions. On each graph, label the wire that was most ductile.

2. Design experiments to test the following questions:

- Did the lengths of the guitar string affect the results of the stretching activity?
- Were the eyebolt wires plastically deformed?

Predictions

Eyebolt wires: Which wire – aluminum, copper or steel – will stretch the most (have the greatest elongation strain)? Which wire will stretch the least (have the least elongation strain)?
Guitar strings: Which string, 1–6, will stretch the most (have the most elongation strain)? Which string will stretch the least (have the least elongation strain)?

Eyebolt Wires

Check one:	*aluminum* ☐	*copper* ☐	*steel* ☐
Length before stretching, cm (A)		**Change in length, cm (B)**	**Elongation strain (B/A)**

Guitar Strings

String #		
Length before stretching, cm (A)	**Change in length, cm (B)**	**Elongation strain (B/A)**

Drawing Conclusions

1. What is the relationship between the type of metal and elongation strain? Explain in terms of crystal structure. Describe verbally or use a series of sketches similar to *Slip Planes*, page 4.

2. What application might increasing the diameter of a wire by wrapping have on the building of suspension bridges? How does the relationship between the diameter of a wire and elongation strain affect a suspension bridge?

Lesson: Collect & Haul

In this lesson, students will develop a position on recycling as a resource and waste management tool by investigating the use of magnets to collect and move ferrous and nonferrous metals.

Objectives

Activity 3. Fluff Stuff

The learner will develop an understanding of the issues of automobile recycling, by:

- recognizing and utilizing principles of magnetism in investigating systems for collecting ferrous metals
- formulating models and hypotheses to explain the interactions of components that affect efficiency of a ferrous metal collection system
- constructing a model of a magnetic drum to simulate collection of ferrous metals from a shredded automobile
- proposing solutions to current challenges for economical total car recycling

Activity 4. Jumping Metal

Given that magnetic attraction of a nonferrous metal may appear to be a contradictory observation of magnetism, the learner will demonstrate a new understanding of the phenomenon, by:

- constructing an aluminum foil electrical circuit to use in testing for magnetic fields
- formulating hypotheses to account for the response of a nonferrous metal to a magnet
- investigating the issue of recycling from a scientific perspective
- comparing the classroom-built aluminum foil circuit to a commercial eddy current separator, and proposing how magnets may be used in recycling nonferrous metals

Key Terms

Key terms are highlighted in the *Background: Student* with definitions provided in the *Glossary*.

alnico	**eddy current**
ferromagnetic	**fluff**
magnetic domain	**magnetic field**

Motivation

Label and display a variety of metallic and nonmetallic items. Ask students to predict whether each item is magnetic or nonmagnetic. Provide magnets to test for magnetic properties and instruct students to sort the items as magnetic or nonmagnetic. Discuss the characteristics of items in both categories. (Magnetic items contain ferrous metals: iron, steel or a high percentage of nickel. Nonmagnetic items do not contain ferrous metals; they may be composed of plastics, paper, minerals, or nonferrous metals such as aluminum, tin or copper.)

Suggestions:

aluminum beverage can
steel food can
cast iron skillet
coil of copper wire
pewter candlestick (pewter is an alloy of tin, sometimes containing lead)
plastic ruler
plastic-coated steel paper clip
steel paper clip
stainless steel butter knife
quartz and/or other mineral rock
variety of foreign and domestic coins, taped on cardboard with mint date face-up; the composition of coins can be found at the local library in publications such as *Standard Catalog of World Coins*, Krause Publications, Iola, WI.

Demonstration

Demonstrate interactions between magnetism and electricity:

- A changing magnetic field creates a current in a wire. Set a galvanometer on a table. Connect the ends of a one-meter copper wire to the galvanometer. Drape the wire over the edge of the table. Move a horseshoe magnet so the internal portion of the magnet passes back and forth across the wire. Instruct the students to observe the galvanometer needle as you move the magnet. Point out that the magnet must be moving to generate a current.

- An electrical current generates a magnetic field. Connect the ends of a wire to the positive and negative poles of a power pack. Turn the power on. Ask students to observe the needle of a compass as you move the compass near the wire. Explain that a compass needle is a long, thin magnet which can be used to detect other magnetic fields.

Content Development

Copy onto transparencies or provide as handouts the figures *Example of Magnetic Equipment Used in Automobile Shredding Scrap Yards*, page 24, and *Example of an Eddy Current Separator*, page 29. Copy and distribute to each student the *Background: Student*, pages 19 and 20. Display the transparencies and use the background reading as references for explaining the use of magnets in processing recyclables for collection and hauling. For more information on principles of magnetism and electricity, refer to a physics text.

Extension

The following activity expands on concepts introduced in this lesson.

Recycling Appliances

Steel is recycled from approximately two-thirds of the appliances in the United States. Contact the Steel Recycling Institute (see *Appendix: Resources*, page 55) or a local solid waste organization to learn which appliances are most commonly recycled.

Divide students into groups and assign each group one appliance to research. Instruct students to prepare a presentation describing the internal workings of the appliance, including the use of permanent and electromagnets, and indicating parts that are recyclable.

Independent Study

- Visit a used auto parts dealer or car demolition facility. Interview personnel to learn more about the process for collecting reusable parts and scrap metal from a car. Research the nearest locations where cars are shredded and inquire about markets for scrap metals.

- Contact a local manufacturing facility or magnet supplier and investigate the uses of magnets in industry. Magnets are used for many purposes, from lifting heavy steel to sweeping nails from the floor.

Evaluation "Test Your Knowledge"

Evaluate student learning of the concepts introduced in this lesson. "Test Your Knowledge" suggestions:

- Create a flow chart of the collection of scrap metals from a shredded automobile. Indicate the use of magnets on the chart. (See *Example of Magnetic Equipment Used in Automobile Shredding Scrap Yards*, page 24.)

- Describe how a magnetic field is induced in the following:

  electromagnet (current moving through a conductive wire wound around a ferro-magnetic core)

  alnico magnet (exposing hot alnico to an electromagnetic field)

  nonferromagnetic metal (inducing a current in the metal by including it in an electrical circuit or by exposing it to a changing magnetic field)

- Look up one or more of the key terms in a reference book other than a dictionary. Write a short paper using the term(s).

Lesson: Collect and Haul

HAVE YOU EVER WONDERED?

How magnets are used to recover both ferrous and nonferrous metals from the 30 million cars recycled every year?

Automobiles are a major source of scrap steel and other metals for recycling into new products. According to a recent article published by the Institute of Scrap Recycling Industries ("Total Car Recycling: Just a Green Dream?" *Scrap Processing and Recycling*, Sept. 10, 1992), nearly 30 million cars throughout the world are recycled every year. Ninety-four percent of the automobiles discarded in the United States are dismantled for reuse or recycling, with 70 percent of the content of each car ultimately recycled ("Carmakers Say Recycling Can Mold Positive Image," *Automotive News*, Nov. 15, 1993).

In preparation for recycling, a car is first drained of all fluids and stripped of parts, such as the radiator and windshield, that can be reconditioned and reused. Following the stripping operation, the car body is flattened and shredded. The shredded material contains ferrous (iron-containing) and nonferrous scrap metals, and other materials such as carpet, insulation, plastic and glass. Virtually all the steel and many other metals are collected from the shredded material and sold for recycling. The material that generally cannot be recycled — the **fluff** — usually is landfilled or incinerated. A goal of many automakers is to further improve economical car recycling by designing new cars for ease of disassembly and recycling.

Magnets play an important role in nearly every phase of collecting and recycling metals from shredded cars.

How a Magnet Works

Every time a magnet is used, a magnetic force is applied. This magnetic force can be either an attractive force, such as the "pull" between a magnet and steel, or it can be a repulsive force, such as the "push" between the like poles of two magnets. All magnets have two poles. When the like poles of two magnets are moved together, north-north or south-south, the magnetic forces repel each other. When the opposite poles of two magnets are moved together, north-south, the forces complement each other and the magnets attract. These repulsive and attractive forces are evident even before the magnets touch, since the magnetic forces surround the magnets. The external area in which magnetic forces can be detected is the **magnetic field**.

Magnetism and electricity are closely linked. A moving magnetic field can produce an electrical current in a conductive material, and an electrical current produces a magnetic field. Because of the nature of metallic bonding, the electrons in any metal move around and between atoms, creating tiny electrical currents and magnetic fields. Usually this motion is random and the metal as a whole does not have a current running through it, nor does it exhibit a magnetic field. In an electrical circuit and in a magnet, however, electron motio.ı is directional, and an electrical current and/or magnetic field is produced.

There are two types of magnets, permanent and temporary. Permanent magnets always contain a **ferromagnetic** material and retain their magnetism for a long time. Iron, nickel and cobalt are the three most important ferromagnetic metals. Many permanent magnets are made of **alnico**, an alloy of iron, aluminum, nickel and cobalt, with minor amounts of other elements such as copper and titanium. Other widely used alloys for making permanent magnets include neodymium-iron-boron and samarium-cobalt. Examples of common permanent magnets are horseshoe and refrigerator magnets.

Temporary magnets may or may not contain a ferromagnetic material and do not retain their magnetism without an external force, such as from another magnet or an electrical current. An example of a temporary magnet is the electromagnet commonly found in telephones and electronic equipment. Electromagnets generally are composed of a conducting wire, usually copper, wound around an

iron-containing core. An electromagnet has a magnetic field only when a current is moving through the wire.

How a Permanent Magnet is Made

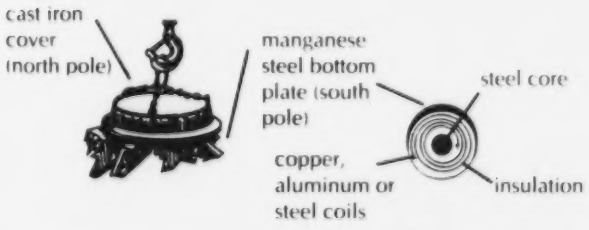
In ferromagnetic materials, the electrons are just the right distance apart and move in just the right way so that the atoms align themselves in regions called **magnetic domains**. These domains have magnetic fields, and can be thought of as miniature magnets. Normally the domains are very tiny (one millimeter or less in any direction) and aligned at random. Without special treatment the material is not a magnet.

The following is an example of a procedure for magnetizing alnico:

- Cast molten alnico in a sand or glass mold. Allow the metal to cool and solidify.
- Heat the metal to approximately 650 degrees Celsius. (This is not hot enough to melt the metal.)
- While hot, place the alnico in an electromagnetic field for one or two seconds.
- Allow the metal to cool. The result is a permanent magnet.

Magnets in Car Recycling

Both permanent and temporary magnets have many applications in car recycling. Lifting the car into the shredder may be accomplished with a lifting magnet, a heavy electromagnet on a crane. A typical lifting magnet contains ribbons of copper, aluminum or steel insulated with paper, plastic or tar, and coiled around a steel core. The outer case of the lifting magnet is usually cast iron on the top and sides, with a heavy manganese steel bottom plate that supports and protects the internal components.

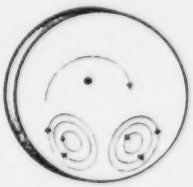


Once the car is shredded, the shredded material is moved by a conveyor past a series of permanent and/or electromagnets to collect the ferrous metals.

Surprisingly, nonferrous metals such as aluminum and copper can also be collected with the help of magnets. These metals normally are not attracted to or repulsed by magnets, but they are conductive materials, and so they can carry an electrical current. Recall that 1) when a conductive material is exposed to a changing magnetic field, an electrical current is induced in the conductive material, and 2) an electrical current produces a magnetic field. Nonferrous metals, therefore, can respond to a magnet when a current is moving through the metal. Some automobile scrap operations and other recyclers make use of this concept in a process called eddy current separation.

Usually we think of an electrical current as moving through a wire in a circuit. An electrical current can also circulate through a larger mass of material, forming a circular pattern which resembles a swirling eddy in a river. This type of electrical current is called an **eddy current**. Like any electrical current, an eddy current produces a magnetic field.

eddy currents in a rotating metal disk



One type of eddy current separator is shown on page 29. This separator consists of an external nonmetallic shell, internal rotor, and belt conveyor. Inside the rotor are permanent magnets arranged so the north and south poles alternate. During operation, the rotor spins at a very high speed, causing a changing magnetic field. The changing magnetic field induces eddy currents (and magnetic fields) in nonferrous metals on the moving conveyor belt. Because of the induced magnetic fields, the nonferrous metals are repulsed by the magnets in the spinning rotor. The repelling forces and forward momentum from the conveyor belt throw the nonferrous metals forward into collection bins. Nonmetal materials merely fall off the end of the conveyor belt, a process commonly called a negative sort.

Activity 3: Fluff Stuff

Objectives

The learner will develop an understanding of the issues of automobile recycling, by:

- recognizing and utilizing principles of magnetism while investigating systems for collecting ferrous metals
- formulating models and hypotheses to explain the interactions of components that affect efficiency of a ferrous metal collection system
- constructing a model of a magnetic drum to simulate collection of ferrous metals from a shredded automobile
- proposing solutions to current challenges for economical total car recycling

Time

One or two class periods

Safety Tips

Advise students to avoid metals with sharp edges when preparing ferrous and nonferrous metals. Students should wear goggles for this activity.

Materials/Equipment

Balance or scale

Cardboard boxes

Coffee cans with both ends removed and two plastic lids

Dowel rods

Ferrous metals (e.g., paper clips, safety pins)

Magnets (strip)

Material for conveyor belt (e.g., newspaper, construction paper, canvas)

Nonferrous metals (e.g., aluminum soft drink tabs, pieces of aluminum foil, bits of copper wire)

Scissors

Paper (shredded)

Plastic (shredded)

Figures/Tables

Average Composition of a U.S.-Built Car, page 23

Example of Magnetic Equipment Used in Automobile Shredding Scrap Yards, page 24

Procedure

1. Copy onto a transparency or use as a handout the table *Average Composition of a U.S.-Built Car*. Review the materials used to build cars.

2. Copy onto a transparency or use as a handout the figure *Example of Magnetic Equipment Used in Automobile Shredding Scrap Yards*. Trace the path of materials from a shredded car through the diagram. Point out the electromagnetic drum, item 2 in the figure. Use the *Background: Student*, pages 19 and 20, to explain the use of magnets in the collection of ferrous scrap metals in the automotive recycling industry.

3. Refer to a physics text and review principles of magnetism, gravity, force and simple machines that are applicable to this activity.

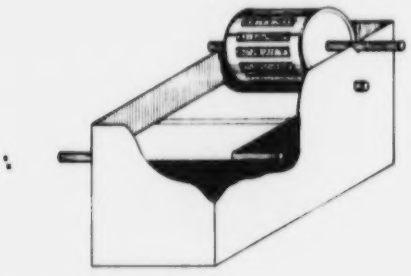
4. Divide the class into lab groups to build a magnetic drum similar to that shown in the figure. Provide each group with a cardboard box, dowel rods, a balance or scale, a coffee can with both ends removed and two plastic lids, material for a conveyor belt, scissors, strip magnets, shredded paper, shredded plastic and assorted ferrous and nonferrous metals.

Note: Students may request additional materials, depending upon the design of the magnetic drum. This activity is designed to build a drum using permanent magnets. More advanced students may wish to build an electromagnetic drum.

Activity 3: Teacher

5. Copy and distribute to each student *Activity 3: Student*, pages 25 and 26. Review the steps for building a magnetic drum and conveyor system for collecting ferrous metals from the fluff. Instruct lab groups to perform the activity. An example of a classroom-built magnetic drum is shown below; however, encourage students to be creative.

An Example of a Classroom-Built Magnetic Drum



6. *For further study:*

- Combine this activity with "What's a MRF?," page 39, or "Sink or Float?" in the *Cycles for Science General Science and Earth Science* curriculum supplement, page 35.

Collecting and Analyzing Data

1. Ask each group to demonstrate and describe their magnetic drum/conveyor system.

2. Lead a class discussion on the physics principles employed in the various designs. Analyze the designs of the most efficient magnetic drum/conveyor systems (the systems that collected the most ferrous metal in the least amount of time and effort). Challenge each group to improve the efficiency of their system, utilizing ideas and information gained from the discussion.

Drawing Conclusions

Q1: Permanent magnets were used to make your magnetic drum. What would be some advantages and disadvantages of using an electromagnet in a magnetic drum? Examine the electromagnets and permanent magnets in the figure Example of Magnetic Equipment Used in Automobile Shredding Scrap Yards, *page 24, items 2, 3, 4 and 5. Describe how the design allows both types of magnets to be used.*

A1: Students should have noticed that the ferrous metals picked up by the permanent magnets had to be removed by hand. The advantages of electromagnets are that they can be turned off to release the ferrous materials and they are capable of lifting heavier loads than permanent magnets. The disadvantages are that electromagnets require a power source and consequently are more expensive to operate. Permanent magnets can be used in the collection of ferrous metals in a scrap yard if, for instance, they are positioned in a conveyor belt. The belt moves the ferrous metals past the magnetic field, allowing the metals to be released.

Q2: Currently, the fluff which remains after ferrous and nonferrous metals are removed must be landfilled or combusted in a waste-to-energy plant. Examine the table Average Composition of a U.S. Built Car, *page 23. Which materials end up in the fluff? What might automakers do to decrease the amount of materials sent to the landfill?*

A2: Design for disassembly and design for recyclability are concepts being considered by automakers for improving the recyclability of cars. These overlapping concepts include:

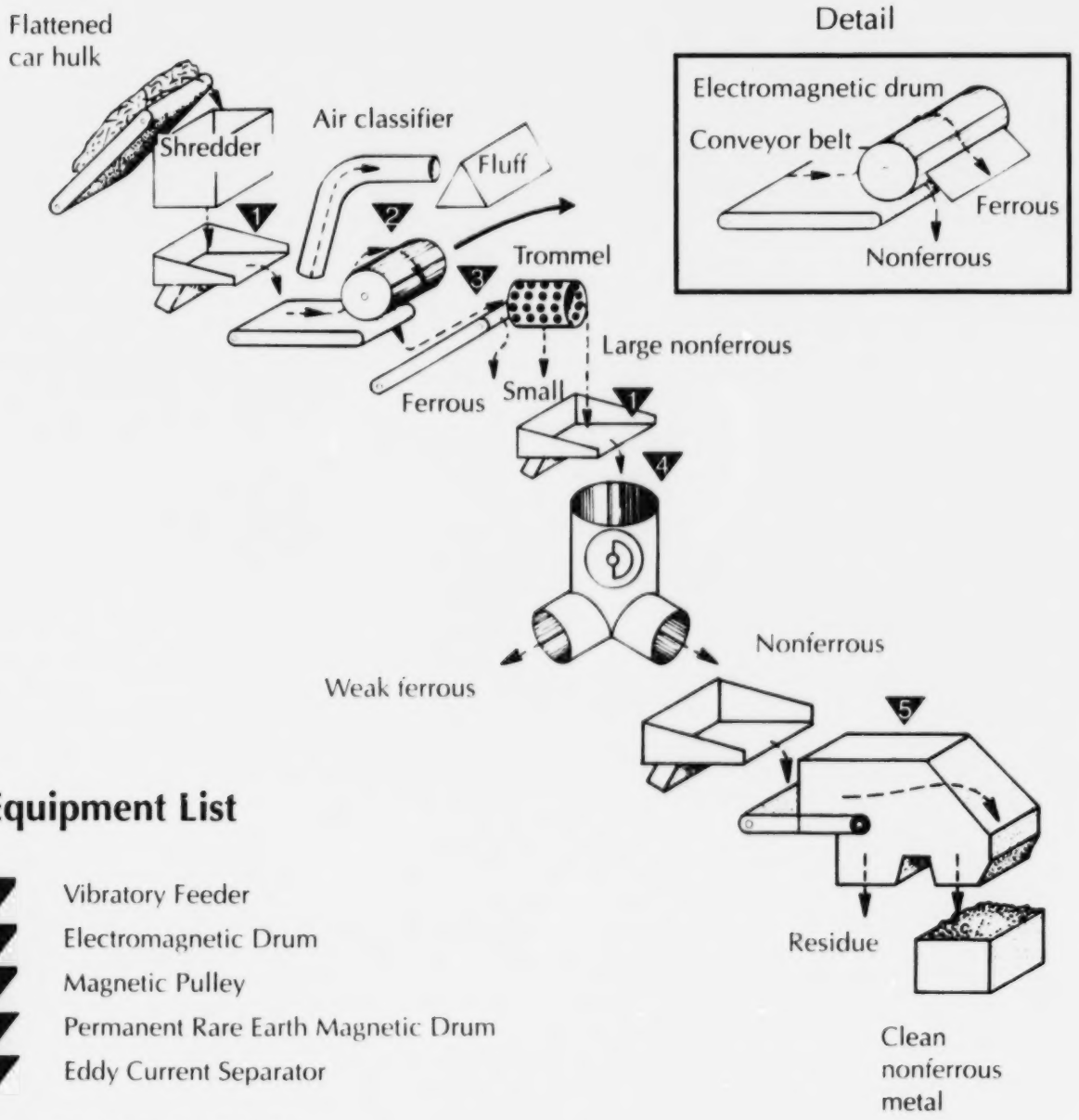
- Easing the removal of whole automotive parts for reuse.
- Eliminating nonrecyclable or hazardous materials.
- Improving recyclability of plastics by reducing the variety used in parts; automakers reportedly draw from a spectrum of more than 120 different types of plastics.
- Avoiding parts that use combinations of materials that are difficult to separate from each other.

Average Composition of a U.S.-Built Car

Material	MASS (kg)	Chemical Composition	Common Properties
Steel			
•conventional (plain carbon)	566	Fe, C, Mn	•range of strengths •heat resistance •can be formable or rigid
•high strength (alloy steel)	106	Fe, C, alloys	
•stainless	15	Fe, Cr, Ni	
•other	24	Fe, C, alloys	
Iron •cast iron	181	Fe, C	•hardness, brittleness •heat resistance •is cast into the desired shape
Aluminum	72	Al	•low density •low strength •high electrical conductivity
Copper	21	Cu	•high electrical conductivity •high thermal conductivity •high corrosion resistance
Zinc die cast	9	Zn	•corrosion resistance
Powder metal	10	assorted metals	•unique combination of properties
Rubber	58	hydrocarbons	•durability
Plastics	101	complex hydrocarbons	•light weight •limited strength •many different types
Fluids	76	petroleum and water based	•varies by fluid
Other materials •Glass •Magnesium •Ceramic •Other	40	 Si, O Mg Al, Si, O, minerals	•varies by material

Source: S.S. Labana, "Recycling of Automobiles," Ford Motor Company, Dearborn, MI, 1990.
Data compiled from production figures for Ford automobiles.

Example of Magnetic Equipment Used in Automobile Shredding Scrap Yards



Equipment List

1. Vibratory Feeder
2. Electromagnetic Drum
3. Magnetic Pulley
4. Permanent Rare Earth Magnetic Drum
5. Eddy Current Separator

Source: Eriez Magnetics, Erie, PA.

Activity 3: Fluff Stuff

Procedure

1. In this activity, you will work in lab groups to build a magnetic drum/conveyor system that will collect ferrous metals commingled with other shredded material, such as would be produced from shredding a car. You will need:

- cardboard box
- dowel rods
- 1 balance or scale
- 1 pair of scissors
- magnets (strip or bar)
- shredded paper
- shredded plastic
- paper (newspaper or construction paper)
- ferrous metals (e.g., paper clips, steel safety pins)
- nonferrous metals (e.g., aluminum soft drink tabs, aluminum foil balls, bits of copper wire)
- coffee can with both ends removed and two plastic lids

Safety Tips: When preparing ferrous and nonferrous metals, avoid metals with sharp edges. Wear goggles for this activity.

2. Prepare commingled recyclable material.

a) Collect a small quantity of each of the following:

- ferrous metal
- nonferrous metal
- shredded paper
- shredded plastic

The amount you use will depend upon the size of the magnetic drum/conveyor system you plan to build. A 500-ml beaker full of plastic and a 250-ml beaker full of each of the others should be adequate for most designs.

b) Mass the ferrous metals. Record the mass in the chart "Mass of Commingled Shredded Materials," page 26.

c) Combine the nonferrous metals, paper and plastic. (The paper and plastic is the fluff.) Record the mass of the nonferrous metals and fluff in the chart "Mass of Commingled Shredded Materials."

d) Mix the ferrous metals with the nonferrous metals and the fluff.

3. Build the magnetic drum.

Refer to the figure *Example of Magnetic Equipment Used in Automobile Shredding Scrap Yards*, page 24, and examine the magnetic drum, item 2 in the figure. Consider principles of magnetism in designing and building your own magnetic drum.

4. Build the conveyor system.

Refer again to the figure *Example of Magnetic Equipment Used in Automobile Shredding Scrap Yards* and examine the conveyor system for moving shredded material past the magnetic drum. Consider the principles of gravity, force, and simple machines in designing and building your own conveyor system. Hint: A conveyor belt requires a small amount of sag to move materials.

5. Assemble the magnetic drum/conveyor system.

Attach the magnetic drum to the conveyor system. Make adjustments to the tightness of the conveyor belt and the height of the drum above the belt.

6. Test efficiency of the ferrous metal collection process.

An efficient system will collect a large amount of ferrous metal in a small amount of time and effort.

a) Conduct a time trial for collecting ferrous metals from the fluff. Record the time of the trial and the mass of ferrous metals and fluff collected in the chart "Collecting Ferrous Metals," page 26.

b) Make adjustments to your magnetic drum/conveyor system to improve efficiency.

c) Conduct two more time trials for collecting ferrous metals. Make adjustments as needed.

Collecting and Analyzing Data

1. Demonstrate and describe to the class your magnetic drum/conveyor system.

2. Participate in a class discussion on the physics principles employed in the various designs. Analyze the designs of the most efficient magnetic drum/conveyor systems (the systems that collected the most ferrous metal with the least amount of time and effort). Use the ideas and information gained from the discussion to make improvements to your own system.

Mass of Commingled Shredded Materials

Material	Mass (g)
Ferrous metals	
Nonferrous metals and fluff	

Collecting Ferrous Metals

Trial	Time (seconds)	Mass of ferrous metals (g)	Mass of fluff (g)
1			
2			
3			

Describe the physics principles used in your design and others.

Drawing Conclusions

1. Permanent magnets were used to make your magnetic drum. An electromagnet requires a power source; a permanent magnet does not. What are some advantages and disadvantages of using an electromagnet in a magnetic drum? Examine the electromagnets and permanent magnets in the figure *Example of Magnetic Equipment Used in Automobile Shredding Scrap Yards*, items 2, 3, 4 and 5, and describe how the design allows both types of magnets to be used.

2. Nonferrous metals are also collected from fluff for recycling. Currently, the material that remains after ferrous and nonferrous metals are removed from a shredded car must be landfilled or burned in a waste-to-energy facility. Examine the table *Average Composition of a U.S.-Built Car*, page 23. Which materials end up in the fluff? What might automakers do to increase recycling and decrease the amount of materials sent to the landfill or a waste-to-energy plant?

Activity 4: Jumping Metal

Objectives

Given that magnetic attraction of a nonferrous metal may appear to be a contradictory observation of magnetism, the learner will demonstrate a new understanding of the phenomenon, by:

- constructing an aluminum foil electrical circuit to use in testing for magnetic fields
- formulating hypotheses to account for the response of a nonferrous metal to a magnet
- investigating the issue of recycling from a scientific perspective
- comparing the classroom-built aluminum foil circuit to a commercial eddy current separator, and proposing how magnets may be used in recycling nonferrous metals

Time

One or two class periods

Safety Tips

Remind students to exercise caution when working with electricity. Review safe techniques for using a power pack. Instruct students to use low voltage for this activity (1.5 - 2 volts).

Materials/Equipment

Aluminum foil
Ammeters *
Connecting wires with alligator clips
Horseshoe magnets (pole separation > 1 centimeter)
Power packs (DC, low voltage)
Scissors

* *This activity may be performed without an ammeter, but an ammeter is recommended to provide visual verification that current is flowing through the aluminum foil.*

Figures/Tables

Example of an Eddy Current Separator, page 29
Scheme of an Aluminum Foil Circuit, page 30

Procedure

1. Copy onto transparencies or use as handouts the figures *Example of an Eddy Current Separator* and *Scheme of an Aluminum Foil Circuit*. Use the transparencies and the *Background: Student*, pages 19 and 20, to discuss the use of magnets in recycling. Review basic principles of magnetism and electricity. For more information on magnetism and electricity, refer to a standard physics text. For more information on car recycling, refer to *Cycles for Science Chemistry*, "Lesson: Collect and Haul."

2. Divide the class into lab groups and provide each group with a 1x40 centimeter strip of aluminum foil, ammeter, horseshoe magnet, small piece of masking tape, power pack and three connecting wires with alligator clips. Students will need to work on a nonconducting surface.

3. Copy and distribute to each student *Activity 4: Student*, pages 31 and 32. Review the steps for constructing an aluminum foil circuit. Show the students the location of the poles on a horseshoe magnet. Instruct lab groups to proceed with the activity.

The following modifications may be made:

If connecting wires with alligator clips are not available, insulated wire with electrical tape may be used. Show students how to strip the ends of the wire and connect the wire to the aluminum foil (and battery, if necessary) with electrical tape.

If power packs are not available, 1.5-volt type D or lantern batteries may be used. Show students how to connect the wires to the positive and negative terminals. Students may need to use electrical tape to hold the wires in place.

If no ammeter is used, instruct students to connect the aluminum foil directly to the power pack or battery.

4. *For further study:*

- Instruct students to predict and test what will happen when the connections to the power pack are reversed while the direction of the horseshoe magnet is constant. (Results will be the same as with reversing the magnet.)

- Label the north and south poles of the horseshoe magnet. Ask students to indicate on the *Scheme of an Aluminum Foil Circuit* the direction of the electrical current and the magnetic field of the horseshoe magnet when the aluminum foil strip is attracted to the horseshoe magnet (moves upward). Ask them to show the direction of the magnetic field of the horseshoe magnet when the strip is repulsed (moves upward, then slightly downward).

- Encourage students to investigate other occurrences of eddy currents. Many pieces of electrical equipment contain masses of metal moving in magnetic fields, and eddy currents may be induced. These types of eddy currents are unwanted because they divert energy and create heat. Eddy current separation for recycling is a positive application of what often is thought of as an undesirable phenomenon.

Collecting and Analyzing Data

1. Instruct students to compare predictions with observations. Ask students whether they encountered any surprises. (Students may predict that the aluminum foil with electrical current moving through it will be attracted to the horseshoe magnet. They may expect the foil to move sideways and adhere to one of the poles of the magnet. They may be surprised to see that the foil "jumps" vertically when the poles of the magnet pass by, and that it does not adhere to either of the poles.)

2. Assist students in constructing a brief summary of their results. Encourage lab groups to share results. (A sample of a summary is as follows: Aluminum which had no electrical current moving through it was not affected by a horseshoe magnet. Aluminum which had an electrical current moving through it "jumped" off the table slightly when the poles of the magnet passed by the foil. When the magnet was reversed, the foil first "jumped," and then moved downward slightly.)

Drawing Conclusions

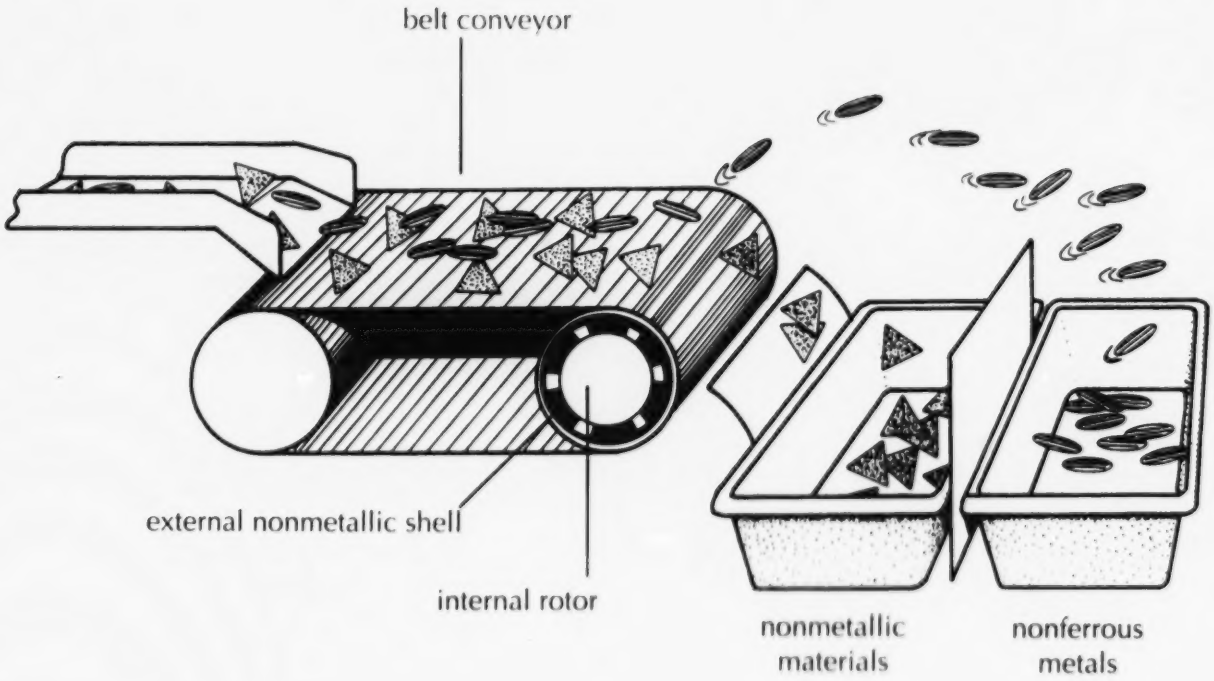
Q1: How are the aluminum foil circuit and an eddy current separator alike? How are they different?

A1: Both the aluminum foil circuit and the eddy current separator involve magnetic fields induced by electrical currents, but the type of current differs. In the aluminum foil circuit, the electrical current is primarily unidirectional, forming part of an external circuit (foil, connecting wires and power pack). In the eddy current separator, the electrical current in the nonferrous metal forms a circular pattern and is not part of an external circuit.

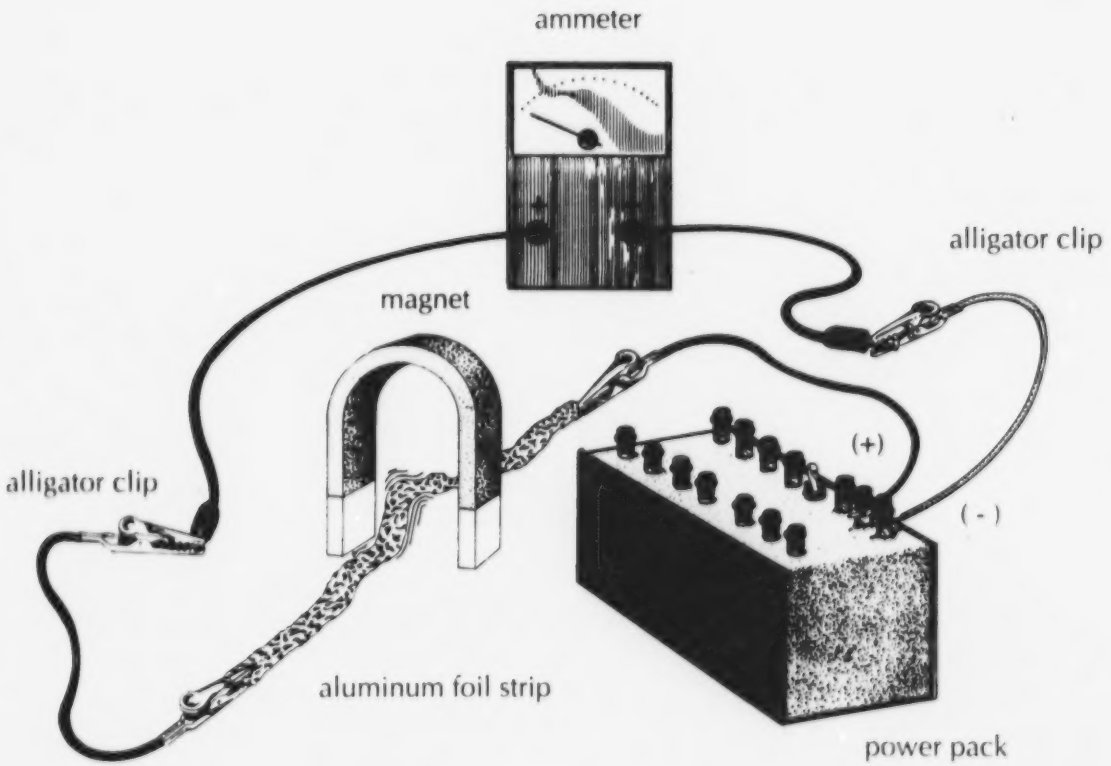
Q2: Nonferrous metals generally do not have the property of magnetic attraction. How, then, are magnets utilized in separating nonferrous metals from automotive fluff?

A2: A magnetic field can be induced in a nonferrous metal by creating an electrical current in the metal. The process of eddy current separation makes use of this phenomenon. Refer to the *Background: Student*, page 20, for a discussion on eddy current separators. For more information contact Eriez Magnetics (see *Appendix: Bibliography*, page 52) and/or a local recycling facility.

Example of an Eddy Current Separator



Scheme of an Aluminum Foil Circuit



Activity 4: Jumping Metal

Procedure

1. In this activity, you will work in lab groups to move a nonferromagnetic metal (aluminum) with a magnet. You will need:

- 1 aluminum foil strip (1x40 cm)
- 1 ammeter
- 1 horseshoe magnet
- 1 small piece of masking tape
- 1 power pack
- 3 connecting wires with alligator clips

Safety Tips: Exercise caution when working with electricity. Utilize safe and proper technique when using the power pack. Use low voltage (1.5 - 2 volts) and perform the activity on a non-conducting surface.

2. Prepare the horseshoe magnet.

Mark one pole of the horseshoe magnet with a small piece of masking tape. It does not matter which pole you mark.

Refer to *Scheme of an Aluminum Foil Circuit*, page 30, to perform the following steps.

3. Set up the electrical circuit without the horseshoe magnet.

a) Check the power pack to be sure the power switch is in the "off" position.

b) Lay the strip of aluminum foil on a nonconducting surface.

c) Clip one end of the first connecting wire to the positive terminal of the power pack (1.5—2 volts). Clip the other end of the wire to one end of the aluminum foil strip.

d) Clip one end of the second connecting wire to the opposite end of the aluminum foil strip. Clip the other end of the wire to the positive terminal of the ammeter.

e) Clip one end of the third connecting wire to the negative terminal of the ammeter. Connect the other end of the wire to the negative terminal of the power pack.

f) Verify that the circuit is set up correctly by turning on the power pack and observing the ammeter. If the needle moves, a current is moving through the circuit.

g) Turn off the power pack.

4. Control: Test for a magnetic field when no electrical current is moving through the circuit.

Record your predictions and observations in the chart "Detecting a Magnetic Field," page 32.

a) Predict what will happen to the aluminum foil strip when you move the horseshoe magnet near the strip without an electrical current moving through the circuit.

b) Predict what will happen when you reverse the horseshoe magnet.

c) Leaving the power off, move the horseshoe magnet so it straddles the aluminum strip as shown in the figure. Move the magnet so the poles move up and down on either side of the aluminum strip. Observe the aluminum foil strip.

d) Reverse the magnet and repeat step c).

5. Test for a magnetic field with an electrical current moving through the circuit.

Record your predictions and observations in the chart "Detecting a Magnetic Field," page 32.

a) Before turning on the power pack, predict what will happen to the aluminum foil strip when you move the horseshoe magnet near it with an electrical current moving through the circuit.

b) Predict what will happen when you reverse the horseshoe magnet.

c) Turn on the power pack. Move the horseshoe magnet so it straddles the aluminum foil strip as shown in the figure. Move the magnet so the poles move up and down on either side of the strip. Carefully observe the aluminum foil strip.

d) Reverse the magnet and repeat step c). Carefully observe the aluminum foil strip.

e) Turn off the power pack.

Collecting and Analyzing Data

1. Compare your predictions with your observations. Identify any differences between predictions and observations.

2. Construct a brief summary of your results. Share your results with other lab groups.

Detecting a Magnetic Field

Record what happens when a horseshoe magnet is moved near an aluminum foil strip with or without an electrical current moving through the strip.		
	Predicted	**Observed**
Control (no electrical current)	**4a)**	**4c)**
	4b) (horseshoe magnet reversed)	**4d) (horseshoe magnet reversed)**
With electrical current	**5a)**	**5c)**
	5b) (horseshoe magnet reversed)	**5d) (horseshoe magnet reversed)**

Drawing Conclusions

1. How are an eddy current separator and an aluminum foil circuit alike? How are they different?

2. Nonferrous metals generally do not have the property of magnetic attraction. How, then, are magnets utilized in separating nonferrous metals from automotive fluff?

Lesson: Sort & Produce

In this lesson, students will examine and develop a position on the recycling process, from sorting to the use of recycled materials in construction, by constructing models of a materials recovery facility and the framework of a house.

Objectives

Activity 5. What's a MRF?

The learner will demonstrate an understanding of the recycling process and its impact on society, by:

- recognizing and utilizing physics principles in exploring the workings of a materials recovery facility (MRF)
- formulating models and hypotheses that may be used to explain the interactions of components within a MRF
- constructing a model of one component of a MRF, and operating it with components constructed by other groups to simulate the sorting of recyclable materials
- proposing scenarios for the role of a MRF in reducing waste and increasing the recycling potential of a community

Activity 6. Steel Home

The learner will identify and discuss structural entities and functions relating to construction, by:

- demonstrating various logical connections between the concepts of tension, compression and the choice of materials for building a house
- formulating hypotheses that can be used to account for regions of stress on a structure
- constructing a model of the framework of a house to investigate the use of recycled steel in construction
- proposing construction materials suitable for use in a full scale building and evaluating the social and ecological impact of using recycled steel

Key Terms

Key terms are highlighted in the *Background: Student* with definitions provided in the *Glossary*.

basic oxygen furnace
commingle
compressive strength
electric arc furnace
materials recovery facility
tensile strength

Motivation

Ask students to take off their shoes, line up the shoes in the front of the room, and return to their seats. Instruct students to wait for your signal, then walk in an orderly fashion to find their shoes and return to their seats. Time this activity. Repeat the activity, but with all the shoes commingled randomly in a heap. Again, time this activity. Compare the length of time and the ease of finding shoes when they were sorted and when they were commingled. Relate this activity to sorting recyclables before and after they are mixed with the trash.

Demonstration

Collect a bag of recyclable paper, plastic, and metals. (Note: glass is also recyclable, but excluded from this activity due to its fragility). Demonstrate methods of sorting these materials. Drop the objects in front of a fan one at a time. Paper and some plastic objects will blow to the side and can be collected in a box. Metals will fall to the ground. Discuss the physics principles involved (e.g., mass, gravity, density). In another demonstration, drop the same objects into a bucket of water and watch the less dense materials float while the more dense objects sink. List other physics principles that could be used to sort recyclables.

Content Development

Prepare transparencies of *Steel Product Forms* and *Tension and Compression on a Beam*, pages 35 and 36. Copy and distribute to each student the *Background: Student*, pages 37 and 38. Use the background reading as a reference in explaining the process for sorting recyclables and producing steel from scrap. Refer to the transparencies as you discuss steel products and the use of structural steel in construction. For more information on making steel, refer to *Cycles for Science Chemistry*, pages 33-36.

Extension

The following activity expands on concepts introduced in this lesson.

Steel Frames

Interview a local builder to find out where steel framed homes and other buildings are being constructed in your area, and what are some of the qualities of steel framing. If possible, visit a construction site and observe the use of I-beams and various structural entities such as columns, trusses and arches. Ask the builder about the careers involved in building a home (e.g., architects, engineers, surveyors, materials buyers, construction workers and managers, real estate agents).

Independent Study

- Contact a local MRF or recycling center to arrange a guided tour. Observe the flow of recyclables as they are dumped on the tipping floor, loaded onto conveyor belts, sorted, and baled or deposited into containers for shipping. Identify the simple machines used in the operation. Discuss with the tour guide the role of the MRF in the local system of waste management. Prepare a presentation to share with the class.
- Research and report on the use of aluminum, brass, brick, concrete, steel and wood in construction of a house. For each material, describe properties that make it suitable for specific uses (e.g., concrete has desirable compressive strength and can be used for foundations and walkways). You are not limited to tension and compression, but may describe any property that is relevant to construction.

Evaluation "Test Your Knowledge"

Evaluate student learning of the concepts introduced in this lesson. "Test Your Knowledge" suggestions:

- Create a flow chart representing the sorting of materials at a materials recovery facility. Start with a commingled mixture of ferrous metals, plastics and nonferrous metals. Indicate the methods and physics principles utilized for sorting the components of the mixture. (Refer to *Example of the Flow of Materials Through a MRF*, page 41.)
- Make a simple drawing of the framework of a house showing the areas of tension and compressive strength.
- Select one or more key terms and write a one page news story.

Steel Product Forms

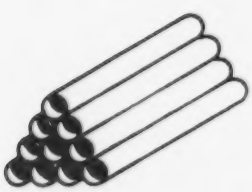
Structural shapes

Rails and joint bars

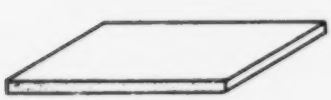
Bars

Wire and wire products

Pipes and tubes

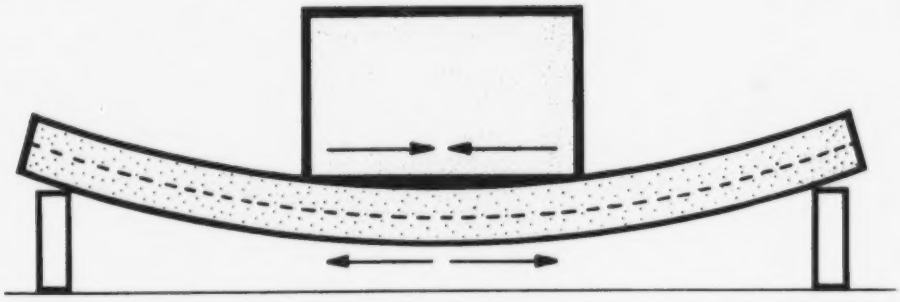


Plates

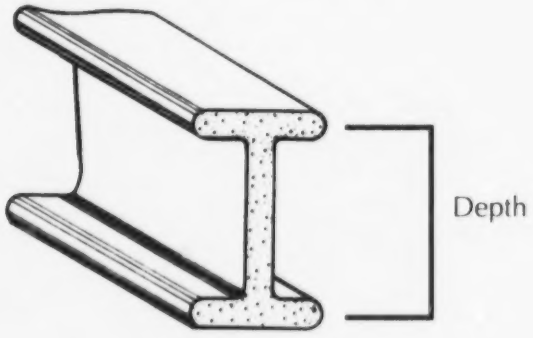


Sheets and coils

Tension and Compression on a Beam



This beam is supported on both ends and carries a load in the middle. The top part of the beam is under compression. The bottom part of the beam is under tension. The middle of the beam is neutral; it is neither stretched nor compressed.



Because the middle of a beam is neutral, less material is needed in this area. Steel beams used in construction often are shaped like the capital letter I. I-beams weigh much less than solid beams of the same depth, yet can support a heavy load.

Lesson: Sort & Produce

HAVE YOU EVER WONDERED?

What happens to recyclable materials after they are picked up from the curb?

Many people are aware of the need to recycle discarded materials in an effort to conserve natural resources and to reduce reliance on landfills. Throughout the United States, many communities offer voluntary or mandatory recycling programs. Residents may either place recyclable materials at the curb, take them to a local drop-off site, or receive payment at a buy-back center. What many people do not know is that collection is just one facet of the recycling process. Recyclables must be processed at the local recycling facility and transported to a manufacturer who will use the materials to make new products. The recycling loop is not complete until the recyclable materials are used to make new products. Consumers must purchase the recycled products to increase the demand and markets for the recyclable materials collected. Otherwise, sorted recyclables must still be disposed of by landfilling or other means.

Separate or Commingled?

Before recyclable materials can be used to make new products, they must be sorted and processed. The manufacturers who purchase the sorted material are looking for high quality material. It is the responsibility of the recycling facility to clean, sort and bale the materials to meet the specifications of the manufacturer.

Recycling facilities use a variety of manual and mechanical means for preparing recyclable materials for shipment to the manufacturer, but the initial sorting and cleaning begins with the resident. The following is a brief scenario of the process of preparing, collecting and transporting recyclables from the home to the manufacturer.

Many homeowners are asked to collect **commingled** recyclables, such as empty steel food, aerosol and paint cans, glass jars, aluminum beverage cans, plastic jugs, soft drink bottles and newspapers. These materials are usually stored in a bag or bin and placed at the curb for pickup.

At the curb, the driver may either perform a partial sort by placing different types of items in separate compartments of the truck, commingle the materials with other materials, or place the commingled bags in a compactor truck. In any case, the recyclables generally are hauled to a recycling processing facility for further sorting and processing. Many communities transport recyclables to a **materials recovery facility** (MRF, commonly referred to as a *murf*).

At the MRF, materials may be separated into containers or placed on a conveyor for either manual or mechanical processing at various sorting stations.

Newspaper and other grades of paper are often sorted manually. Commingled glass, aluminum cans, steel cans and plastic bottles may be sorted using a combination of manual and mechanical techniques.

As the commingled mixture moves along the line, the ferrous metal (steel) is pulled out with magnets and loaded into a container to be baled, shredded, or otherwise processed for shipping. The plastic (called the "light fraction") may be initially pulled out by vacuum or blower, or sorted by hand, followed by an additional sort to separate the plastic into type, such as HDPE (gallon jugs) and PETE (soft drink bottles). Once sorted, the plastic is mechanically compacted and baled.

Glass is separated manually by color. Aluminum continues to move down the line and eventually falls off the end into a container to be densified (made more dense by compaction).

All along the sorting stream, workers must be attentive to ensure the materials are effectively sorted. For instance, if a glass jar should end up in the steel, aluminum, or plastic stream, it must be pulled out by hand. Each of these materials must be separated in order to sell the material to a manufacturer of new products. Much of the sorting process is labor intensive, but machines are used whenever possible to make the job easier and to increase output.

Keep in mind that this is just one example of how commingled recyclables might be processed. Different facilities may utilize a number of different ways to process these materials.

Once the recyclables are sorted and baled, the bales are loaded onto trucks and shipped to manufacturers who will perform the final step in the recycling process—manufacturing new products from the recycled materials. Purchase of these recycled products by the consumer is important for providing momentum to the cycle.

Producing Steel from Scrap

According to the International Iron and Steel Institute, world consumption of finished steel in 1991 was 628 million metric tons, comprised of 304 million metric tons of recycled scrap steel and 324 million metric tons of new steel. The United States is a major exporter of scrap steel. The source of the scrap is steel from recycling programs such as the curbside program previously described, and from scrapped vehicles, appliances, and construction materials.

Scrap steel obtained from various recycling programs is charged (loaded) into a furnace for melting into new steel. Two widely used furnaces for making steel are the **electric arc furnace** and the **basic oxygen furnace.**

The electric arc furnace makes steel with virtually 100 percent scrap steel. It contains large graphite electrodes through which an electric current is passed, creating high heat that melts the scrap. The molten steel may go to a metallurgy facility where a variety of treatments are performed to adjust the composition, allowing steel to be manufactured to exact specifications.

A typical basic oxygen furnace makes steel with as much as 29 percent scrap steel. The remainder of the raw material comes from liquid iron produced from iron ore. The furnace derives its name from the fact that oxygen is injected into the molten material in the furnace, starting a series of reactions that creates molten steel.

Once molten steel is produced by either the electric arc or basic oxygen techniques, it is cast in stationary molds or continuously cast into long slabs and moved through a series of shaping, heating and cooling processes to produce a variety of sizes, shapes and types of solid steel. Steel product forms include structural shapes, rails, bars, wire, pipe, plate and sheets, as shown in the figure *Steel Product Forms*, page 35. All steel manufactured in the United States contains recycled steel.

Structural Steel

Steel is especially useful as a construction material because it has both high tensile and compressive strength combined with good ductility and toughness. **Tensile strength** is the ability to withstand stress due to tension (stretching). **Compressive strength** is the ability to withstand stress due to compression (squeezing).

Steel has been widely used in commercial and industrial construction for many years. Recently, steel framing has attracted interest in the construction of private homes. Steel is strong, relatively light weight (compared to wood), and can be manufactured to the exact size and quality needed, which reduces waste and helps control costs. Because structural steel is made from recycled scrap steel that can be recycled again when the home is demolished, it is an environmentally sound choice for construction.

Activity 5: What's a MRF?

Objectives

The learner will demonstrate an understanding of the recycling process and its impact on society, by:

- recognizing and utilizing physics principles in exploring the workings of a materials recovery facility (MRF)
- formulating models and hypotheses that can be used to explain the interactions of components within a MRF
- constructing a model of one component of a MRF, and operating it with components constructed by other groups to simulate the sorting of recyclable materials
- proposing scenarios for the role of a MRF in reducing waste and increasing the recycling potential of a community

Time

One to two class periods

Safety Tips

If tools are used, demonstrate proper use. Avoid the use of sharp objects in the design and in the recyclable mixture. Students must wear goggles and gloves.

Materials/Equipment

Assorted construction materials (see Procedure Step 2)

Assorted tools (see Procedure Step 2)

Recyclable materials:

aluminum foil (rolled into 1-centimeter balls)
aluminum soft drink tabs
copper wire
paper (shredded)
paper clips (steel)
plastic grocery bags (shredded)
polystyrene packing particles
safety pins (steel)

Figures/Tables

Example of Flow of Materials Through a MRF, page 41
Scheme of a Mechanical Mini-MRF, page 42

Procedure

1. Copy onto a transparency or use as a handout *Example of Flow of Materials Through a MRF*. As you show the figure, explain that a MRF is a facility for processing commingled (mixed together) recyclables. Describe the flow of materials through the various sorting stations. Identify the properties of each type of recyclable material (e.g., mass, magnetism) that impact the design of each sorting station. For more information on MRFs, refer to the *Background: Student*, pages 37 and 38.

2. As a class, decide on dimensions of the mini-MRF. Divide the class into lab groups. Assign each group one station of the mini-MRF to design and operate:

- Conveyor to move materials
- Blower to sort out the light fraction (paper, plastic)
- Magnet system to sort out ferrous metals (paper clips, safety pins)
- Flotation system to sort nonferrous metals from each other

The following are suggestions for creating a simple, manually operated MRF:

- Conveyor — Tape together sections of newspaper to make the conveyor belt. Drape the belt around a table.
- Blower — Make fans of construction paper.
- Magnet system — Attach bar magnets to the bottom of a non-coated, steel cookie sheet.
- Flotation — Position a plastic tub of water at the end of the conveyor. Use a kitchen strainer to scoop off materials that float.

For more information on flotation systems, refer to "Background: Student" and "Sink or Float," *Cycles for Science General Science and Earth Science*, pages 33-38.

3. Prepare the recyclable materials.

Commingle a quantity of each of the recyclable materials listed in "Materials/Equipment." Provide each group with a small amount of the commingled recyclables with which to test their designs as they develop them.

4. Copy and distribute to each student *Activity 5: Student*, pages 43 and 44. Review the steps and instruct lab groups to proceed with the activity.

Note: An alternative activity is to challenge each group to design its own desktop mini-MRF, 60 centimeters square or smaller.

5. *For further study:*

- Quantify effectiveness of the sorting process. Mass each recyclable material prior to commingling. After each trial run, assist groups in calculating the percentage of material collected at their stations and others, using the formula:

$$\frac{\text{mass of each item sorted properly}}{\text{total mass of that item}} \times 100$$

- Mechanize the MRF. Encourage students to think of methods for reducing the manual labor involved in sorting materials. Refer to *Scheme of a Mechanical Mini-MRF* for ideas.
- Create a video presentation to share with other student groups. Produce an interesting and scientifically accurate story about a MRF and the sorting process. Use the development of the classroom MRF, including processes that did not work and how problems were overcome, to reinforce physics concepts while promoting awareness about the challenges and solutions of recycling.

Collecting and Analyzing Data

1. Instruct students to sketch and label the improved mini-MRF in the chart "Designing a Mini-MRF," page 44.

2. Encourage students to make a log of the development of their stations in the chart "Designing a Mini-MRF." Ask them to include a description of the original design, rationale for the design, improvements made to the design and suggestions for additional improvements. Allow groups to discuss observations and outcomes with other groups.

Drawing Conclusions

Q1: Which principles of physics apply in the operation of a MRF? Cite examples.

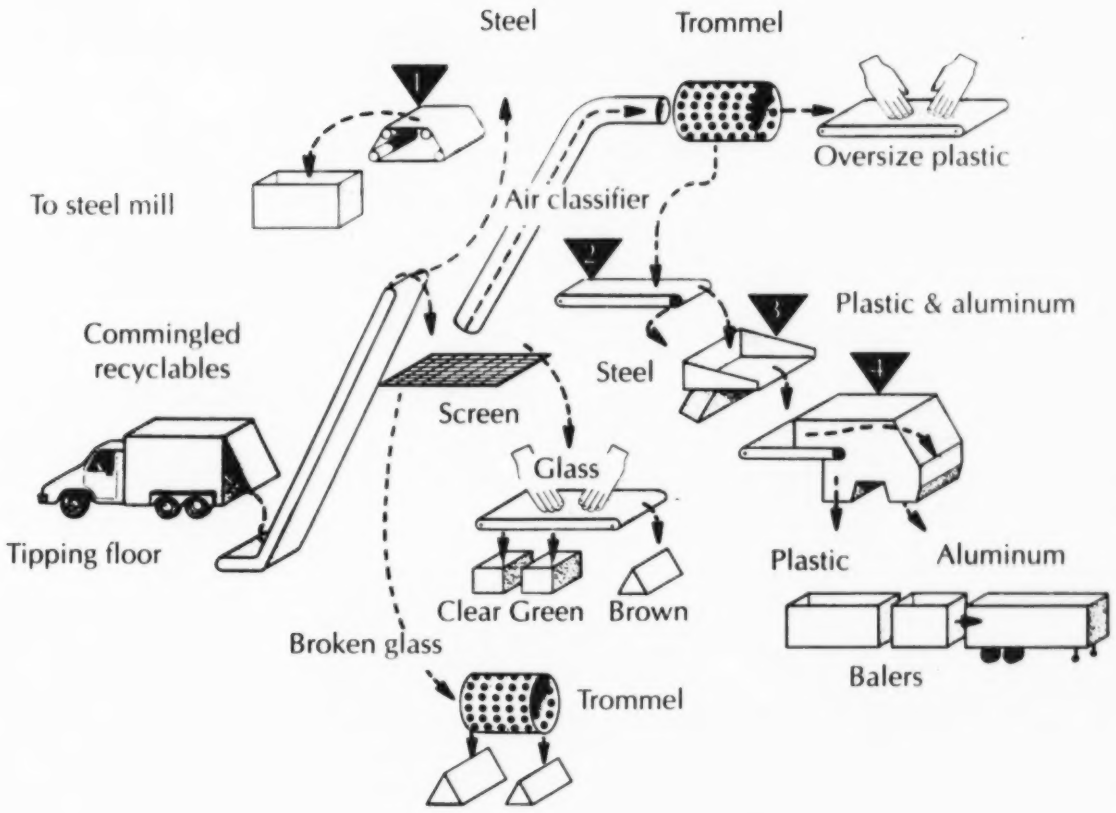
A1: Students may refer to *Example of Flow of Materials Through a MRF* or to their own mini-MRFs. Physics principles include work and motion (conveyor carrying materials down the line), magnetism (sorting ferrous metals), gravity (materials falling off the conveyor), density (flotation and sorting of light fraction) and electricity (powering air classifiers and conveyors).

Q2: Your mini-MRF sorted a small volume of commingled materials. A large scale MRF may sort tons of materials per hour. What problems do you think a large scale MRF might have with sorting? (Consider such factors as materials compaction and labor.) How might these problems be solved?

A2: A large scale MRF dealing with tons of materials may have a problem with compression. Compressed materials do not sort as easily as loose materials. To overcome this problem, some MRFs utilize the "waterfall" effect. Materials are moved on a series of conveyors positioned in such a way that materials cascade over the edge of one belt onto another one underneath. The tumbling motion loosens materials for easier sorting.

Operation of a commercial MRF can be labor intensive, which can contribute significantly to costs. Some MRFs have mechanized portions of the sorting process, but still require manual sorting of materials for which automated sorting is not available. For instance, plastics as a whole may be removed from the commingled mix mechanically, but different types of plastics must be separated from each other by hand.

Example of Flow of Materials Through a MRF

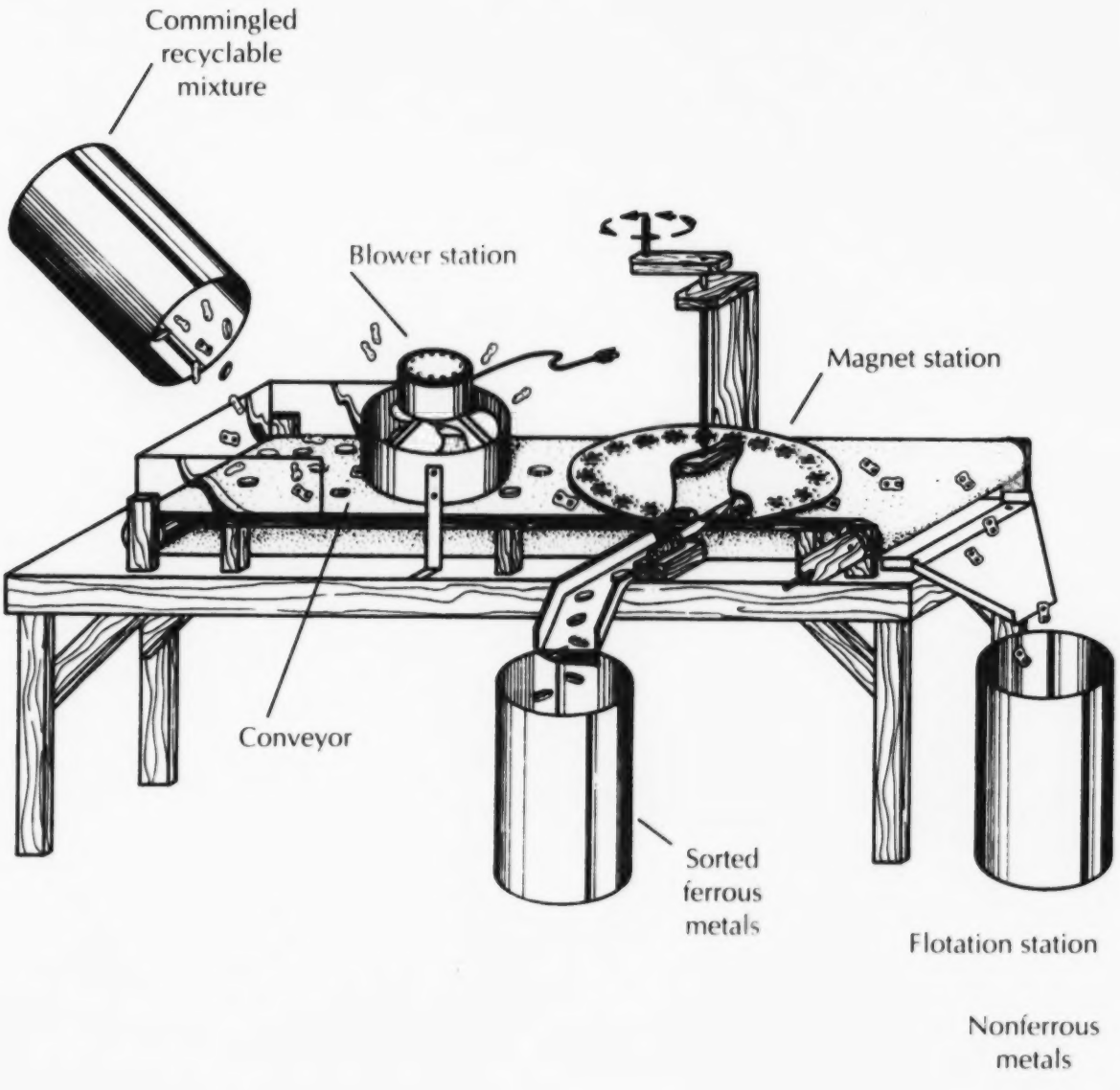


Equipment List

1. Belt Magnet
2. Magnetic Pulley
3. Vibratory Feeder
4. Permanent Magnetic Eddy Current Separator

Source: Eriez Magnetics, Erie, PA.

Scheme of a Mechanical Mini-MRF



Designed by: Charles R. Laymon

Activity 5: What's a MRF?

Procedure

1. In this activity, you will work in lab groups to design and build a small scale, functional Materials Recovery Facility (MRF). You will need a small amount of commingled recyclables:

- light fraction (plastic, paper)
- ferrous metals (paper clips, safety pins)
- nonferrous metals (aluminum foil, aluminum soft drink tabs, copper wire)

Safety tips: Use safe and proper technique for handling tools. Avoid the use of sharp objects in your design and the commingled recyclables. Wear goggles and gloves for this activity.

2. As a class, decide on dimensions of the mini-MRF. Your teacher will assign your group one of the following mini-MRF stations to design and operate:

- Conveyor to move materials
- Blower to sort out the light fraction (paper, plastic)
- Magnet system to sort out ferrous metals (paper clips, safety pins)
- Flotation system to sort nonferrous metals from each other

3. Design and build your station using the materials available to you. Examples of materials you might use include newspaper, masking tape, construction paper, kitchen strainers, cookie sheets and bar magnets. Be creative!

4. When all stations are completed, work with other lab groups to assemble the mini-MRF and participate in performing a trial run. Make a visual assessment of the efficiency of the mini-MRF. Consider how much of the material was sorted correctly and how much time it took to sort it properly. Note any problem areas. Record your observations in the chart "Operating a Mini-MRF," page 44.

5. Work with your lab group to make improvements to your station. As a class, participate in performing a second trial run and again evaluate efficiency.

Collecting and Analyzing Data

1. Sketch the improved mini-MRF in the chart "Designing a Mini-MRF," page 44. Label the stations.

2. Make a log of the development of your station in the chart "Designing a Mini-MRF." Include a description of your original design with your rationale for designing it that way, and any improvements you made to make your design more efficient. Also include ideas for additional improvements. Share your log with other groups.

Operating a Mini-MRF

Trial	Observations
1	
2	

Designing a Mini-MRF

Sketch the improved mini-MRF. Label the stations.
Make a log of the development of your station or your desktop mini-MRF, including original design, rationale and improvements. Indicate ideas for additional improvements.

Drawing Conclusions

Q1: Which principles of physics apply in the operation of a MRF? Cite examples.

Q2: Your mini-MRF sorted a small volume of commingled materials. A large scale MRF may sort tons of materials per hour. What problems do you think a large scale MRF might have with sorting? (Consider such factors as materials compaction and labor.) How might these problems be solved?

Activity 6: Steel Home

Objectives

The learner will identify and discuss structural entities and functions relating to construction, by:

- demonstrating various logical connections between the concepts of tension, compression and the choice of materials for building a house
- formulating hypotheses that can be used to account for regions of stress on a structure
- constructing a model of the framework of a house to investigate the use of recycled steel in construction
- proposing construction materials suitable for use in a full scale building and evaluating the social and ecological impact of using recycled steel in construction

Time

Two class periods

Safety Tips

Warn students to exercise caution when bending wire hangers. A wire hanger bent under tension can act as a spring and snap back into position. Instruct students to manipulate the whole hanger and not attempt to cut, break or take apart the hanger. Students must wear goggles and work gloves.

Materials/Equipment

Cardboard (corrugated, 30-centimeter squares)
Dumbbells or discs (0.5, 1.5 and 2.5 kilograms)
Hammers
Modeling clay
Nails (5-centimeter)
Plastic drinking straws (non-flexible)
Pliers
Plywood (30-centimeter squares)
Scissors
Styrofoam sheets or blocks
Tape (electrical or masking)
Wire hangers

Figures/Tables

Steel Product Forms, page 35
Tension and Compression on a Beam, page 36
Strengths of Materials, page 47
Structural Entities, page 48

Procedure

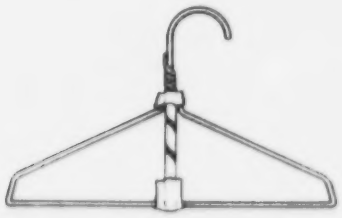
1. Copy onto transparencies or use as handouts the figures/tables listed above. Use the *Background: Student*, pages 37 and 38, and the figure *Steel Product Forms* to explain steelmaking and the use of recycled steel as a construction material.

2. Refer to the figure *Tension and Compression on a Beam*, page 36. Point out the locations of tension and compression on the beam. Refer to a physics text for more information on tension and compression. Show the figure *Strengths of Materials* and compare tensile and compressive strengths of some common materials.

3. Show the figure *Structural Entities* and describe how columns and trusses help support a load. Perform these simple demonstrations:

- *Cylinder* Stand a sheet of loose-leaf paper on edge and let it go, to demonstrate that a flat sheet of paper cannot support its own weight. Roll the sheet of paper into a cylinder and secure with tape. Stand the cylinder on edge and carefully place a physics text on top as shown. As a cylinder, the paper will now support both its own weight and the additional weight of the physics text. Point out that a plastic drinking straw is a cylinder.

- *Truss* Place the bottom edge of a wire coat hanger on a table and have a student press down on the handle. The hanger will not support a heavy load. Cut notches in the ends of a plastic drinking straw and tape the ends of the straw to the wire coat hanger as shown. Have the student press down on the handle. The hanger will now support a heavy load.



4. Divide the class into lab groups. Provide each group with a sheet of plywood, four nails, two 30-centimeter square sheets of corrugated cardboard and twelve wire hangers for the primary building materials. Also provide each group with a hammer, pliers and a pair of scissors.

Furnish a supply of plastic drinking straws, styrofoam, modeling clay and electrical or masking tape for groups to choose as supplemental building materials.

Have additional building materials on hand for groups to use for experimentation.

5. Copy and distribute to each student *Activity 6: Student*, pages 49 and 50. Review the steps for designing, building and testing the structures. Instruct groups to perform the activity.

Collecting and Analyzing Data

1. Display houses built by various groups in the class. Instruct students to predict which house is the strongest, tallest and most efficient. Ask them to explain their reasoning.

2. Observe which house is the strongest, tallest and most efficient by organizing a contest.

- Strength — Set a 0.5 kilogram dumbbell on the second floor of the structure. Increase the mass one dumbbell at a time until the structure becomes unsteady.
- Height —Measure with a meter stick.
- Efficiency (minimum of building materials)— Estimate visually or mass the structures.

Instruct students to record in the chart "Strong, Tall and Efficient," page 50, which house ranked the highest and why. Encourage groups to analyze the winning designs and discuss ways to improve or modify their own designs.

Drawing Conclusions

Q1: Where were the areas of the greatest tension and compression in your final design? Indicate these areas on the sketch, and explain how your design did or did not strengthen these areas.

A1: Students should indicate horizontal beams and flooring as areas subjected to the greatest tension, and support beams and columns as bearing the greatest compression. Distributing the load over additional support columns is one way students may have strengthened these areas.

Q2: Which materials in the table Strengths of Materials *might be used in areas of tension? Compression? What are some advantages of using steel to frame a house or building?*

A2: Students will be familiar with the use of wood in framing and may use wood as a reference point. The tensile strengths of brick and concrete are less than wood and they cannot be used in areas of tension. The compressive strengths of brick and concrete are greater than wood and they can be used in areas of compression. Nylon and human bone are added to the table for interest.

Advantages of using steel in framing include high tensile and compressive strength, recyclability, low cost compared to other metals and lumber, and light weight compared to lumber.

Strengths of Materials

(Force/Area)

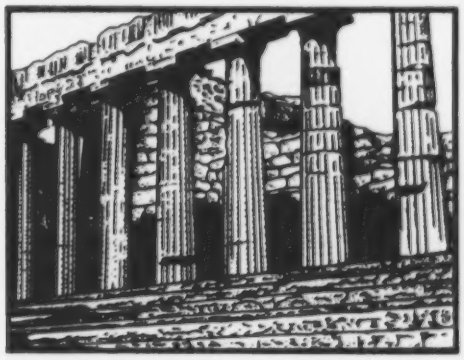
Material	Tensile strength (N/m^2)	Compressive strength (N/m^2)
Steel	5.0×10^8	5.0×10^8
Brass	2.5×10^8	2.5×10^8
Aluminum	2.0×10^8	2.0×10^8
Concrete	0.02×10^8	0.20×10^8
Brick	*	0.35×10^8
Wood (pine)	0.40×10^8	0.25×10^8
Nylon	5.0×10^8	*
Human bone	1.3×10^8	1.7×10^8

***very little strength**

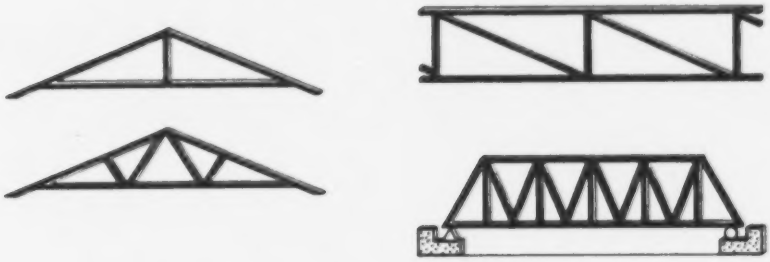
Source: Martindale, David G., Robert W. Heath and Philip C. Eastman. *Fundamentals of Physics: A Senior Course*. Heath: Canada, 1986.

Structural Entities

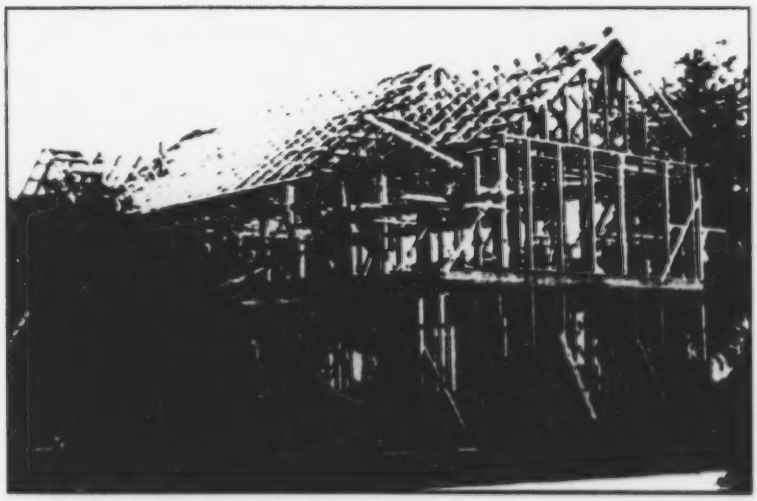
Columns



Trusses



Steel Framed House



Activity 6: Steel Home

Procedure

1. In this activity, you will work in lab groups to design and build a model of the framework and floors of a two-story house. You will need:

- 1 dumbbell (0.5-kg)
- 2 sheets corrugated cardboard (30-cm square)
- 1 hammer
- 4 nails (5-centimeter)
- 1 pair of pliers
- 1 piece of plywood (30-centimeter square)
- 1 pair of scissors
- 12 wire hangers

You may choose from the following, depending upon your design:

- modeling clay
- plastic drinking straws
- styrofoam
- tape (electrical or masking)

Safety tips: Exercise caution when bending wire hangers; a hanger bent under tension can act as a spring and snap back into position. Do not attempt to cut, break, or take apart the hangers. Wear goggles and gloves for this activity.

2. Design and build your two-story house.

a) Refer to *Structural Entities*, page 48, for ideas for designing a strong, stable structure.

b) Consider the following when designing your structure:

- The house must be strong enough to support a minimum of 0.5 kilograms placed on the floor of the second story. The ability to hold additional mass is a plus.
- The house must be as tall as possible without sacrificing strength and stability.
- The house must be efficient (requiring a minimal amount of building materials).

c) Begin construction by making the base of the house. Stretch a hanger to form a square. Fasten the hanger to the plywood by driving a nail part way into the plywood at each corner of the hanger, and bending the nail over the hanger to secure it.

d) Construct the walls and ceilings with wire hangers. Use cardboard for the floors. Modeling clay, styrofoam, masking tape, and straws may be used to improve the strength and stability of the structure.

e) Make a sketch of your house in the chart "Design of a Two-Story Structure," page 50.

3. Test your design.

a) Place the 0.5 kilogram dumbbell on the floor of the second story to test the strength of the structure.

b) If needed, remove the dumbbell and make adjustments to increase the strength and stability of the structure. Include the modifications in your sketch of the house.

c) Repeat step a) and make further adjustments if needed.

Collecting and Analyzing Data

1. Examine the structures built by various groups in the class. Predict which house will be strongest, tallest and most efficient. Record your predictions in the chart "Strong, Tall and Efficient," page 50, and explain your reasoning.

2. Participate in a contest to determine the strongest, tallest and most efficient house:

- Strong — Set a 0.5 kilogram dumbbell on the second floor of the house. Increase the mass one dumbbell at a time until the structure becomes unsteady.
- Tall — Measure with a meter stick.
- Efficient — Visually estimate the quantity of building materials used, or mass the structure.

In the chart "Strong, Tall and Efficient," record which house ranked highest in these areas, and why. With your group, discuss ways to further improve your own design.

Design of a Two-Story Structure

Sketch your initial design. After testing, use arrows to indicate weak spots and describe what happened. Sketch in your modifications and describe improvements made to the design.

Strong, Tall and Efficient

Record which house is the strongest, tallest and most efficient. Explain your reasoning.	
Predicted	**Observed**

Drawing Conclusions

1. Where were the areas of the greatest tension and compression in your final design? Indicate these areas on the sketch, and explain how your design strengthened these areas.

2. Which materials in the table *Strengths of Materials* might be used in a full scale building in areas of tension? Compression? What are some advantages of using steel to frame a house or building?

Glossary

alnico a permanent magnet alloy containing iron, nickel, aluminum and cobalt.

basic oxygen furnace a steelmaking furnace in which oxygen is injected into molten metal; typically uses about 25-29 percent scrap steel.

cementite a phase of steel in which carbon is dispersed throughout the metal as cementite (Fe_3C), like grains of pepper mixed in salt, distorting the crystal and making the steel hard.

commingle mix together. Commingled recyclables can include some or all of the following: brown, green, and clear glass; aluminum; steel cans; various plastics; office paper, newspaper, magazines; yard waste.

compressive strength the ability to withstand stress due to compression (squeezing).

deformation a change in shape of a metal or other material caused by application of a force so that atoms move from their original positions to new positions. **Elastic deformation** is temporary; **plastic deformation** is permanent.

eddy current an electrical current induced by an alternating magnetic field and forming a circular pattern.

elastic limit the distance beyond which a material that is being stretched will not return to its original shape; the material is on the verge of becoming permanentiy deformed.

electric arc furnace a steel-making furnace in which an electric current is used to melt the metal; uses virtually 100 percent scrap steel.

elongation strain the ratio of the change in length to the original length of a metal that is subjected to a stress.

ferrite a phase of steel in which a small percentage of carbon exists in spaces between iron atoms, distorting the shape of the crystal and making steel hard.

ferromagnetic a material which has significant magnetic properties similar to iron. Iron, cobalt and nickel are ferromagnetic.

fluff the material from shredded automobiles which remains after ferrous metals are collected magnetically; contains nonferrous metals and nonmetal materials such as plastics, glass, rubber, carpet and dirt.

hardness a measure of the resistance of a metal to plastic deformation.

magnetic domain a small region of a ferromagnetic material in which the atoms are aligned to form a small magnetic field.

magnetic field the area external to a magnet in which magnetic forces can be detected.

martensite a very hard steel produced by quick cooling, or by adding certain alloying elements with normal cooling.

materials recovery facility a facility for sorting, separating and processing recyclables for shipment to a manufacturing facility.

phase a micro-region in a sample of steel; examples are ferrite, cementite and martensite.

quench to cool very rapidly, such as by plunging in water.

slip planes the layers of atoms in a metal crystal which slide past each other when a force is applied.

temper to increase toughness (reduce brittleness while maintaining much of the hardness) by applying heating and cooling treatments.

tensile strength the ability to withstand stress due to tension (stretching).

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Did You Know? Steel Recycling

- For each ton of steel recycled, 2500 pounds of iron ore, 1000 pounds of coal, and 40 pounds of limestone are saved.

- Through all of its recycling efforts, the steel industry saves an average of 600 trillion Btu's each year, the energy equivalent to electrically power more than 18 million households for a year.

- Steel cans account for more than 90 percent of the food can market, four percent of the beverage can market and the majority of the paint and aerosol can markets.

- Steel products, such as cars, containers and appliances, contain about 25 percent recycled steel; heavy products, such as structural beams and plates used in construction, contain virtually 100 percent recycled steel.

- Already, more than 66 percent of all steel in the U.S. is recycled into new products. Cars, appliances, machinery and even demolished buildings provide a constant supply of steel scrap that is used to produce new steel.

- Steel is used in construction to build homes, factories, stores, office buildings and transportation systems. This dependable, durable, affordable material is the heart of the American way of life.

- Consumers have relied on the steel can for the preservation of fruits and vegetables, longer shelf life and tamper resistance. Often called "tin" cans, steel cans come in approximately 600 sizes, shapes and styles, containing over 2,500 different products.

- For decades, bridge builders have selected steel to expand the world's ground transportation systems. Over the years, new, higher strength steels have been developed, including those with chemical properties that inhibit corrosion and deterioration.

- Steel, because of its structural uses, is often unseen. Steel nails, screws, and bolts hold together our homes, schools and offices, and have for generation after generation.

- Steel is now used for framing houses as well as providing the structure for commercial buildings.

- Today's automobiles offer many steel applications: corrosion-resistant coated sheet steels in body panel configurations, and steel bars used in axles, gears, bearings, drive trains, engine parts, and steering and suspension assemblies. Steel wire also forms integral parts of the whole car as it serves to operate and control the vehicle. Steel tubing helps to reduce weight and cuts production costs.

- During the 19th century, iron and steel made possible the development of the American transcontinental railroad system. Steel formed our nation's arteries - it carried railroad systems across the nation and roads across the rivers. The "iron horse" of yesterday was known for its relative speed and reliability. Today's modern rail transportation maintains that reputation in a faster-paced world. And steel continues to be the material of choice for building the systems that link people and products across the country.

- One hundred years ago, steel in construction made possible the first skyscrapers to be built. Continuing advances in architectural design and steel technolgy make it possible to use less steel to build larger, taller, stronger and more flexible structures.

Resources

Aluminum Recycling Association
1000 16th Street, NW, Suite 400
Washington, DC 20036
202/785-0550

American Forest and Paper Association
1250 Connecticut Avenue, NW, Suite 200
Washington, DC 20036
202/463-2420

American Iron and Steel Institute
1101 17th Street, NW, Suite 1300
Washington, DC 20036
202/452-7100

American Plastics Council
1275 K Street, NW, Suite 500
Washington, DC 20005
202/371-5319

Aseptic Packaging Council
1000 Potomac Street, NW, Suite 401
Washington, DC 20007
202/333-5900

Association of Home Appliance Manufacturers
20 N Wacker Drive
Chicago, Ill 60606
312/984-5800

Automotive Recyclers Association
3975 Fair Ridge Drive
Suite 20, Terrace Level N
Fairfax, VA 22033-2906

Can Manufacturers Institute
1625 Massachusetts Avenue, NW
Washington, DC 20036
202/232-4677

Glass Packaging Institute
1627 K Street, NW, Suite 800
Washington, DC 20006
202/887-4850

Institute of Scrap Recycling Industries
1325 G Street, NW
Washington, DC 20005
202/466-4050

Keep America Beautiful, Inc.
Mill River Plaza, 9 West Broad Street
Stamford, CT 06902
203/323-8987

National Recycling Coalition, Inc.
1101 30th Street, NW, Suite 305
Washington, DC 20007
202/625-6406

National Wildlife Federation
1412 16th Street, NW
Washington, DC 20036
202/797-6800

Steel Recycling Institute
680 Andersen Drive
Pittsburgh, PA 15220-2700
412/922-2772

Teacher Evaluation

Please return evaluation form to:

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Steel Recycling Institute
680 Andersen Drive
Pittsburgh, PA 15220-2700
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In future editions of *Cycles for Science/Physics*, we plan to include the average time in minutes for each activity. In the box below, please record the number of minutes it took for your class to complete each activity.

	Minutes		Minutes		Minutes
Quenched and Tempered Steel	_____	Fluff Stuff	_____	What's a MRF?	_____
Stretch and Strain	_____	Jumping Metal	_____	Steel Home	_____

We value your comments on the ***Cycles for Science*** curriculum. Please enclose a copy of any or all of the lessons with your comments and changes marked in red. If you have added curriculum or teaching aids, please enclose photocopies with an explanation.

Make further comments on a separate page.

If we use your comments or ideas to improve the curriculum supplement, you will be credited in the acknowledgements of the 2nd edition of ***Cycles for Science / Physics.***